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ARCHIVES OF SURGERY

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VALUE OF BLOOD AMYLASE ESTIMATIONS IN THE DIAGNOSIS OF PANCREATIC DISEASE

A CLINICAL STUDY *

ROBERT ELMAN, M.D.

NORMAN ARNESON, M.D.

AND

EVARTS A. GRAHAM, M.D.

ST. LOUIS

The clinical diagnosis of disease of the pancreas [1] has always been fraught with great difficulty. Whether one is dealing with the dramatic suddenness of an acute hemorrhagic pancreatitis, the silent jaundice in carcinoma at the head of the pancreas, the variable and indefinite symptomatology of chronic pancreatitis or the insidiously developing pancreatic cyst, a large proportion of pancreatic lesions remain unrecognized clinically and are first diagnosed at laparotomy or at postmortem examination. This is not because the pancreas is so rarely the seat of disease, for it is diseased far more frequently than is generally supposed. Among the 60,000 patients admitted to Barnes Hospital but 150, or 0.25 per cent of the cases, bore a diagnosis of pancreatic disease of one kind or another, exclusive of diabetes mellitus, while among the last 3,600 autopsies performed at the Washington University School of Medicine, gross or microscopic lesions of the acinar tissue were found in 113, or in 3 per cent of the cases. This is in substantial agreement with the observations of others.[2] On the other hand, a more frequent incidence is reported by Moench,[3] who found acute pancreatitis alone in 2 per cent of routine autopsies.

Many efforts have been made to test the function of the pancreas in the attempt to recognize disease of it clinically. Tests of kidney and of liver function have been so fruitful of results that a similar usefulness seemed possible in the case of the pancreas. The literature concerning

* Submitted for publication, June 20, 1929.

* From the Department of Surgery, Washington University School of Medicine, and Barnes Hospital.

1. Only disease of the external secretion is here considered. Glycosuria as a sign of lesion in the islets, when noted, was secondary to disease of the acini and ducts.

2. Barron, M.: Disease of Pancreas, Pathologic Study, with Report of Cases, Arch. Int. Med. **35**:807 (June) 1925.

3. Moench, G. L.: Acute Pancreatitis with Erosion of Splenic Artery and Fatal Hemorrhage, J. A. M. A. **82**:360 (Feb. 2) 1924.

these attempts is extensive. In a recent monogaph on pancreatic disease,[4] fourteen different tests for pancreatic function were described; several more exist which were not mentioned. The majority of them, however, have fallen into desuetude and at present have only a historical interest.

In this paper, consideration will be confined to the amylase content of the blood serum, since this starch-splitting ferment is one of the prominent enzymes elaborated by the pancreas, and because it lends itself readily to quantitative measurement. Moreover, many observers have studied it in the attempt to correlate deviations from the normal with the existence of pancreatic disease. The methods used have been various, and the great variability in the observations may be ascribed, in part at least, to this circumstance.

PREVIOUS OBSERVATIONS

A starch-splitting ferment, diastase, or more accurately, amylase, was first found in the blood by Magendie in 1846. Although diastase was extensively studied as it occurred in the vegetable kingdom, the first attempt to measure it quantitatively in the animal organism was made by Foster [5] in 1867. Among other things, he found that in the blood from six diabetic patients there was no deviation from the diastatic activity of normal blood. The details of his quantitative method were not recorded.

The nature of the various sources of amylase occurring in the animal organism next attracted the attention of physiologists. From the work of a series of observers, summarized by Carlson and Luckhardt [6] in 1908, it was established that the amylase in the blood had the same properties as that present in the lymph, saliva, liver and pancreas; that is, it had the power to break down starch to the dextrins and finally to dextrose. The concentration of the ferment was found to be greatest in the pancreas and least in the cerebrospinal fluid.

The origin of the amylase found in the blood is of special interest and has been the object of much work and some difference of opinion. Carlson and Luckhardt [6] believed, on the basis of their own observations, that it was merely a by-product of general tissue metabolism. They found no change in blood amylase in three cats following pancreatectomy, an observation confirmed by Bainbridge and Beddard [7] in one cat, and by Milne and Peters [8] in several dogs. Many workers found greater amounts in the blood leaving than in that entering the

4. Gross, O., and Guleke, N.: Die Erkrankungen des Pankreas, Berlin, Julius Springer, 1924, p. 39.

5. Foster, M.: J. Anat. & Physiol. **1**:107, 1867.

6. Carlson, A. J., and Luckhardt, A. B.: Am. J. Physiol. **23**:148, 1908.

7. Bainbridge, F. A., and Beddard, A. P.: Biochem. J. **2**:89, 1907.

8. Milne, L. S., and Peters, H. L.: J. M. Research **26**:415, 1912.

liver, and concluded that the liver manufactures the ferment. Carlson and Luckhardt,[6] on the contrary, found no difference in amylase concentration in blood from the hepatic artery and vein. Davis and Ross[9] adduced further evidence that the liver did not manufacture diastase. When they administered toxic amounts of chloroform to dogs, a marked decrease in blood amylase was found, but since no change occurred in depancreatized dogs, they concluded that the decrease in the first experiments was due to toxic changes in the pancreas rather than in the liver.

The pancreatic origin of blood amylase was first promulgated by Schlesinger,[10] who found in two dogs and one cat a diminution or a disappearance of the enzyme in the blood after pancreatectomy. King[11] found a uniform decrease or disappearance of urinary amylase and a decrease in the blood from one half to one third of the normal level in four dogs and two cats after pancreatectomy. Wohlgemuth,[12] Moeckel and Rost,[13] Lepine,[14] Kaufmann,[15] Gould and Carlson,[16] Otten and Galloway,[17] and Davis and Ross[9] have all had similar results. Moreover, Schlesinger found from three to four times as much ferment in blood leaving the pancreas as in the general circulation, an observation confirmed by Wohlgemuth. King, as further evidence of the pancreatic origin of at least part of the blood amylase, showed that the amount of the ferment in puppies and kittens increased from a low level at birth to the normal adult value at 6 weeks of age. This fits in with the observations of Korowin,[18] who found no amylase in the human pancreas at birth and an increasing amount after the second month up to 1 year of age, when it reached the normal adult concentration. That the salivary gland does not contribute to the presence of blood amylase is indicated by his observation that its content of diastase is large and remains the same from birth on. Schlesinger,[10] moreover, in extirpations of the salivary glands in dogs, found no significant change in the blood. The observations of King,[11] published in 1914, and also those of Davis and Ross[9] are probably of greater value than those of others because they used a more accurate quantitative method. Amylase was measured by the time required to effect a given change in the starch solution rather

9. Davis, L. H., and Ross, E. L.: Am. J. Physiol. **56**:22, 1921.

10. Schlesinger, W.: Verhandl. d. Kong. f. inn. Med. **25**:505, 1908; Deutsche med. Wchnschr. **34**:593, 1908.

11. King, C. E.: Am. J. Physiol. **35**:301, 1914.

12. Wohlgemuth, J.: Verhandl. d. Kong. f. inn. Med. **25**:501, 1908.

13. Moeckel, K., and Rost, F.: Ztschr. f. physiol. Chem. **67**:433, 1910.

14. Lepine, R., and Barral, M.: Compt. rend. Acad. d. sc. **113**:729, 1891.

15. Kaufmann, M.: Compt. rend. Soc. de biol. **46**:130, 1894.

16. Gould, L. K., and Carlson, A. J.: Am. J. Physiol. **29**:165, 1912.

17. Otten, H., and Galloway, T. C., Jr.: Am. J. Physiol. **26**:347, 1910.

18. Korowin: Malys Jahresb. **3**:158, 1873.

than by the amount of change effected in a given time, following thus the technic of Roberts,[19] reported in 1881, and more recently shown by Bayliss [20] to be the most reliable principle in measuring such a ferment as amylase.

The evidence thus far seems to point to the pancreatic origin, in part at least, of blood amylase and to lend a theoretical basis to attempts to correlate deviations from the normal concentration of this enzyme in the blood with the existence of pancreatic disease. Other experimental facts add further support to this association.

Ligation of the pancreatic ducts in animals leads to a prompt increase in the concentration of blood amylase, as shown in an experiment performed by Schlesinger,[10] Clerc and Loeper,[21] King,[11] Wohlgemuth,[12] Gould and Carlson [16] and others with uniform results. King [11] noted a return to normal in about a week, but at autopsy found that the ligatures had slipped and that the ducts were functioning again. In unpublished data from this laboratory we have demonstrated a fourfold increase in blood amylase within fifteen minutes after clamping of the tube that drained all of the pancreatic juice in dogs. This increase rose to a point seventy-five times greater than the normal in twenty-four hours, after which the concentration gradually fell to normal in two weeks. No dogs were observed after this length of time. Autopsy showed a hard, enlarged pancreas with beginning atrophy of the acini. It is difficult to keep a dog alive longer than this after careful and complete obstruction of the ducts. We did not, therefore, study the blood amylase at a time when the acini were fully atrophied.

The clinical investigation of blood amylase has been rather extensive. One of the most widely used methods is that of Wohlgemuth [22] which depends for its end-point on the complete hydrolysis of starch as revealed by the disappearance of the blue color which it produces with iodine. In thirty normal persons, Wohlgemuth [12] himself found "considerable fluctuation" (no numerical values being reported). In twenty patients with a variety of conditions Schlesinger [10] found variations expressed by numerical values between 10 and 25. In fifty cases, Von Benczur [23] reported differences too great to be of diagnostic value (from 16 to 250) except in one case of obstruction of the pancreatic duct in which the value was considerably higher than in the others (500). The observations of other workers were more promising. Thus Corbett,[24] in 1912,

19. Roberts, W.: Proc. Roy. Soc. Med. **32**:145, 1881.

20. Bayliss, W.: Theory of Enzyme Action, New York, Longmans Green & Company, 1924, ed. 5, p. 52.

21. Clerc, A., and Loeper, M.: Compt. rend. Soc. de biol. **66**:871, 1909.

22. Wohlgemuth, J.: Biochem. Ztschr. **9**:1, 1908.

23. Von Benczur, J.: Wien. med. Wchnschr. **23**:890, 1910.

24. Corbett, D.: Quart. J. Med. **6**:351, 1912.

found that the values were constant in normal persons and that the value of blood amylase was unchanged by diet. Stafford and Addis [25] and Cohen [26] and Stocks [27] similarly reported a uniformity in the concentration of "normal" human blood amylase.

An alternative method for determining blood amylase has been used by many. It depends, not on the disappearance of starch, but on the formation of sugar which is measured quantitatively by some method of copper reduction. Kaufmann,[15] and Moeckel and Rost [13] were the earliest to use this method on blood serum. The latter workers found that feeding had no influence on the value of blood amylase, that a prolonged fast resulted in some increase, and that although different species varied considerably, individuals among the same species differed little from each other, observations which were in general agreement with the work of others. Reid [28] reported uniform values for human beings, varying between numerical values of 6 and 10, Meyer and Killian [29] values between 15 and 17, and Lewis and Mason [30] between 15 and 25, all using the sugar reduction method.

Definite deviations from the normal in pancreatic disease have been reported by many writers. Stocks [27] studied sixty-five cases and found an increased blood amylase in carcinoma of the pancreas, nephritis and chronic passive congestion, and in three of eight cases of diabetes. Meyer and Killian [29] recorded an increase from the normal value 15 to values from 41 to 75 in diabetes and to values from 30 to 52 in nephritis, the latter varying in general with the degree of retention of nitrogen. Lewis and Mason,[30] however, following the same technic, failed to confirm these observations in cases of diabetes; while variations were noted in nephritis, there was no correlation with the type of disease or with its progress.

The lack of uniformity in the clinical observations briefly summarized is probably due to several factors. Discrepancies in the methods used have undoubtedly a good deal to do with many of the differences. In the beginning of our studies on blood amylase, we tried the starch-iodine as well as the sugar reduction method, and found both unsatisfactory for reasons already mentioned.[31] The method finally adopted applied a new principle to the study of amylase, and it is one which, we believe, has yielded more consistent results. Another factor in the results of

25. Stafford, D. D., and Addis, T.: Quart. J. Med. **17**:151, 1924.

26. Cohen, I.: Brit. J. Exper. Path. **6**:173, 1925.

27. Stocks, P.: Quart. J. Med. **9**:216, 1916.

28. Reid, C.: Brit. J. Exper. Path. **6**:314, 1925.

29. Meyer, V. C., and Killian, J. A.: J. Biol. Chem. **29**:179, 1917.

30. Lewis, D. S., and Mason, E. H.: J. Biol. Chem. **44**:455, 1920.

31. Elman, R., and McCaughan, J. M.: Quantitative Determination of Blood Amylase with Viscosimeter, Arch. Int. Med. **40**:58 (July) 1927.

other writers is the fact that in but few instances was the clinical diagnosis confirmed by operation or autopsy. In the series of cases here reported, with two exceptions, each diagnosis depended on the observations at laparotomy or on postmortem examination.

EXPERIMENTAL WORK

The determination of amylase was made by a new method which apparently has never been used before for the measurement of the ferment in blood. It is based on the rate of diminution of the viscosity of a starch solution, as described in a previous paper.[31] The method enables one to follow quantitatively and continuously the course of the diastatic reaction, that is, the breaking down of starch to dextrose, for each step of the reaction involves, of course, the hydrolysis of larger to smaller molecules and hence a reduction of viscosity.

This circumstance has two immediate advantages: First, every step of the diastatic reaction becomes measurable at the same time. In the Wohlgemuth method[22] the disappearance of starch is the only step considered, whereas in that of Moeckel and Rost[13] it is only the final production of sugar that is measured. It is obvious that the enzyme may attack any part or all of the chain and at varying rates. It is thus impossible without extensive work to tell whether all the starch is hydrolyzed first or whether only a part of it is attacked and carried all the way to dextrose. By measuring the viscosity all stages of the reaction become detectable at one time.

The second advantage lies in the fact that one can use time as a measure of enzyme concentration, which is the most accurate correlation since an enzyme acts on the rate of reaction. As pointed out by Bayliss,[20] in case of a reaction proceeding in steps, ferment concentration is best estimated by the time required to effect a given change rather than by the amount of change effected in a given period of time. By the method used in this study, it was possible to do this. An arbitrary amount of change was selected (20 per cent reduction in viscosity), and the amount of amylase then became a function of the time required to effect this change.

A final advantage of the present method lies in its objectiveness. The measure of time was made by a stop-watch, and the difficulty of selecting a color change as in the Wohlgemuth method was obviated.

For the use of the method one needs: (1) the set-up for measuring viscosity, that is, the viscosimeters, and (2) the preparation of a solution, or rather a suspension, of starch of constant composition.

Viscosimeter.—The instrument used is of the type originally designed by Ostwald. It is U-shaped with a capillary tube and bulb inserted into one arm (fig. 1). The starch solution (5 cc. of a 3 per cent solution) is introduced into

one arm of the tube and, by suction on a rubber tube, is drawn above the upper mark into the other arm, whereupon the suction is released. As the level of the fluid passes this point the stop-watch is started, and as the second mark just below the bulb is passed the watch is stopped. This time interval (in seconds) is taken as the measure of viscosity. Viscosimeters were selected which had an outflow time for water of from 15 to 20 seconds, or for the starch solution of from 40 to 50 seconds. This short period enables one to make more rapid readings and gives values as accurate as those with tubes having a much longer outflow time. Several readings are made to check the constancy of the viscosity, and

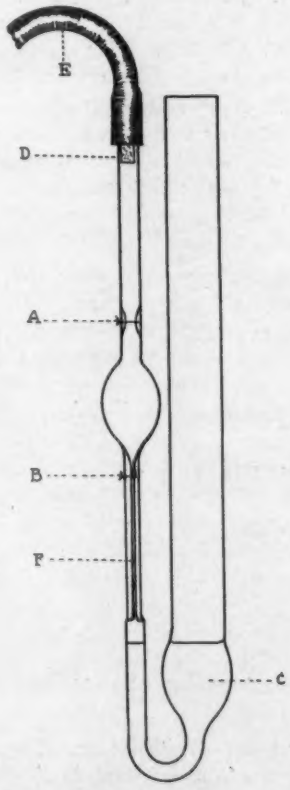

Fig. 1.—The Ostwald viscosimeter. Solution *C* is introduced into the open end of a glass U-tube. By suction on rubber tube *E*, it is drawn above point *A* and the suction is removed. The time of outflow from point *A* to point *B* is taken as a measure of the viscosity (in seconds). The resistance is due to the capillary tube *F*. A plug of cotton *D* protects the solution from contamination by particles of saliva.

ordinarily 0.4 cc. of the plasma to be tested is added. A few bubbles of air are blown through to insure mixing, and readings are made every few minutes until there is a 20 per cent reduction in the outflow time, that is, in the viscosity. The number of minutes required to reach this point is recorded. A graph may be plotted if desired with viscosity in seconds, and time in minutes, as axes. It

forms almost a logarithmic curve, and, as reported in our previous communication [21] this time interval, in minutes, bears an inverse linear relation to the amount of amylase added, that is, the reaction follows Arrhenius' rule, $T = \frac{1}{Q}$, where T equals the time required to effect a given change and Q equals the concentration of enzyme used to effect this change. The addition of 0.4 cc. of blood plasma to 5 cc. of starch solution affects the initial viscosity so little that no correction is necessary for the zero point. This is due to the fact that the blood plasma has about the same viscosity as the starch preparation that we used. In the case of plasma with higher concentrations of amylase a smaller amount may be added, that is, 0.1 instead of 0.4 cc.

The set-up is represented in figure 2. A water-bath with glass sides is used, the back wall being frosted. A light behind it gives satisfactory illumination. The water is kept in circulation by air blown through it, and the temperature is maintained at 37.5 C. ± 0.1 C. by means of a mercury thermostat and a small gas flame. The viscosimeters, as well as all pipets, are plugged with cotton to preclude the entrance of particles of saliva. All glassware is kept scrupulously clean, for any adhering particle may affect the passage of fluid through the capillary tube. As a routine, the following solutions are run through before being used each time: cleaning solution, tap water, alcohol and ether.

Starch Solution.—We found variations in the composition of various preparations of soluble starch, so that for any series of observations it is necessary to obtain a good supply and to use the same preparation throughout. The batch that we are now using is made up as follows: Three grams are weighed out and added to 70 cc. of cold distilled water and shaken until the suspension is homogeneous. It is then brought to boil over a free flame, with constant shaking, in not less than three minutes, although a longer period does not alter the properties of the final solution. Thirty cubic centimeters of Sörensen's fifteenth-molar phosphate buffer is added (p_H 6.8), and the flask is stoppered with a cotton plug and autoclaved for fifteen minutes at 10 pounds' (4.5 Kg.) pressure. Just before it is ready to use it is filtered through paper, and 5 cc. portions are transferred to the viscosimeters. The solution, if kept sterile at 37 C., may stand for from several hours to a day or two without altering its usefulness, but if kept for several days changes seem to occur. Blood is obtained by venipuncture; it is oxalated, and the clear plasma used. Standing in the icebox for from twelve to twenty-four hours does not alter its diastatic power, but longer periods may do so.

Calculation of Amylase Units.—With 0.4 cc. of normal oxalated plasma from the human adult a reduction of 20 per cent in the outflow time is effected in about thirty minutes, or with 0.2 cc. in sixty minutes. One unit is arbitrarily taken as the amount of enzyme in 1 cc. which will reduce the viscosity 20 per cent in one hour. The formula for determining amylase units (A.U.) on this basis is $A.U. = \frac{60}{T.V.}$, which is simply Arrhenius' rule with the factor of concentration added. In the foregoing formula, $A.U.$ equals units per cubic centimeter, T time (in minutes) required to reduce the viscosity 20 per cent and V volume of enzyme solution (plasma) used to effect this change.

It was found convenient to have a solution of saliva or of pancreatic juice diluted so that 0.1 cc. of it was as active as 0.4 cc. of normal human serum. It keeps well in the icebox for several months or more, provided a crystal of thymol is added. In this way a standard control was available at all times without the necessity of obtaining normal plasma.

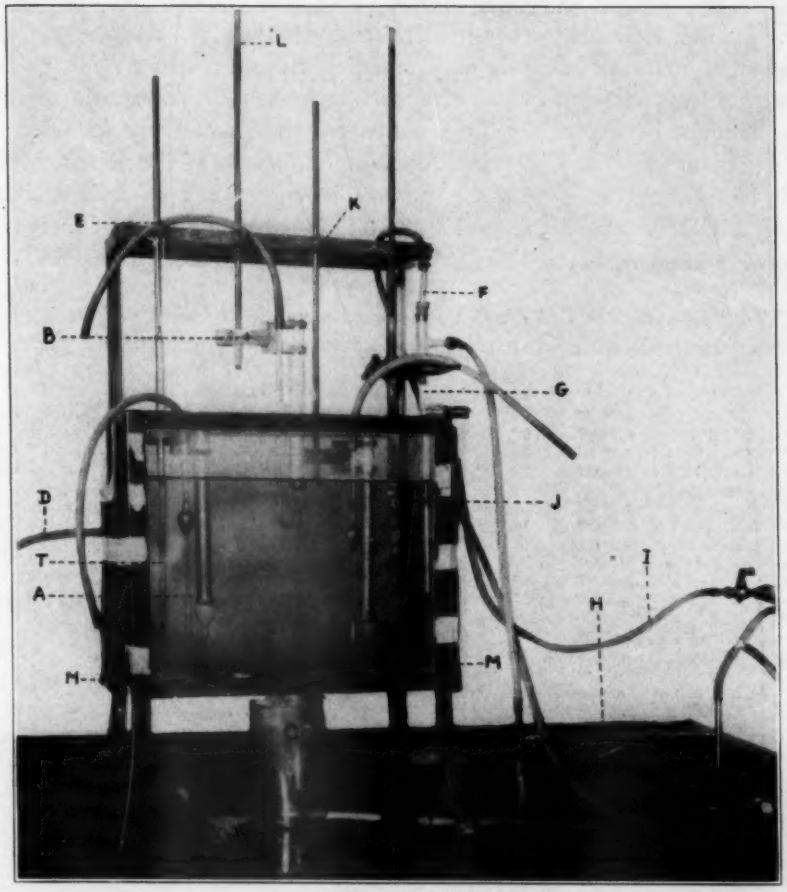

Fig. 2.—Viscosimeter set-up for amylase estimations. The Ostwald viscosimeter *A* is attached to a brass spring clamp *B* which in turn is fastened to the brass rod *L*, movable in the frame and held tight by the screw *K*. In this way the viscosimeter may be lowered into or removed from the water bath. The solution in the viscosimeter is drawn up to the upper mark by suction on the rubber tube *E*. A desk lamp *D* illuminates the bath from behind.

The water bath is kept warm by the gas flame *C* which is automatically regulated through the mercury thermostat *G*. The gas inlet F is a tube drawn to a capillary point which is placed just at the level of the mercury when the temperature *T* is at 37.5 C. A by-pass *H* keeps a tiny pilot light always burning. The water bath is insulated on each side by felt pads *M*, and the water is kept in circulation by an inlet of air *I* which bubbles through a glass tube *J*.

OBSERVATIONS

We have prepared tables and clinical abstracts of our observations which are almost self-explanatory. The observations on the blood amylase in a series of twenty-five "normal" controls, not operated on, are presented in table 1. The only criterion of normality so far as the pancreas was concerned was that no suggestion of pancreatic disease was evident in any case. Two patients with diabetes are included in this list since they too gave no indication of disease of the acinar tissue. The blood amylase in all cases was within what we have designated as "normal" limits, that is, from 4.3 to 6.8 units, although most of the cases showed values within a closer range than this. In table 2 are listed data

TABLE 1.—*Amylase Units in the Plasma of a Series of Unselected Patients*

	Case	Date	Age	Sex	Diagnosis	Amylase Units
1	(M. J.)	4/22/27	31	F	Early pregnancy	4.5
2	(J. W.)	4/22/27	58	M	Cataract	5.0
3	(R. S.)	4/23/27	24	M	Hernia	4.5
4	(A. T.)	4/23/27	28	M	Bronchiectasis	5.1
5	(R. H.)	4/23/27	19	M	Tuberculosis of the hip	4.7
6	(L. B.)	7/10/27	54	F	Diabetes	6.0
7	(M. E.)	7/16/27	16	F	Deformity of the nose	6.1
8	(R. M.)	7/10/27	45	M	Colostomy	5.5
9	(A. B.)	8/ 8/27	30	M	Normal	4.8
10	(J. S.)	9/23/27	38	M	Fracture of the spine	6.2
11	(M. L.)	10/27/27	24	F	Dislocation of the neck	6.5
12	(M. P.)	11/ 1/27	29	F	Hysteria	5.4
13	(S. S.)	11/ 9/27	61	M	Prostatectomy	6.8
14	(J. H.)	1/23/28	45	M	Sarcoma of the humerus	6.5
15	(A. H.)	2/16/28	30	M	Bronchiectasis	4.8
16	(J. D. B.)	2/20/28	60	M	Arteriosclerosis	6.2
17	(E. H.)	2/20/28	30	F	Pernicious anemia	6.0
18	(T. T.)	3/ 5/28	24	M	Hernia	4.3
19	(C. W.)	3/13/28	50	F	Carcinoma of the breast	6.2
20	(M. R.)	3/13/28	42	F	Intestinal fistula	5.0
21	(R. T.)	3/25/28	72	F	Pulmonary tuberculosis	6.0
22	(A. W.)	10/13/28	42	F	Carcinoma of the breast	6.5
23	(A. R.)	10/25/28	68	M	Arteriosclerosis	5.5
24	(A. G.)	2/ 4/29	52	F	Diabetes	6.0
25	(L. P.)	10/29/28	28	M	No diagnosis	4.8

for thirty-four patients subjected to laparotomy or autopsy in which the pancreas was examined; striking differences in amylase concentration are shown between eleven of them which were "normal" and twenty-three in whom disease of the pancreas was found. Further details of the "normal" patients are summarized in table 3. It will be noted that the condition in a number of them, on account of the presence of jaundice, had been diagnosed as carcinoma at the head of the pancreas. The diagnosis of "normal" pancreas was made by histologic examination in four of these eleven cases at autopsy.

Clinical abstracts of these thirty-four cases in which an operation or an autopsy was performed are appended. In addition, two other patients are described (nos. 35 and 36); on one with pancreatitis, who died, we were unable to perform an autopsy, and in the other pancreatitis was

TABLE 2.—*Summary of Observations on Blood Amylase* in Cases Coming to Operation or Autopsy*

Case	Normal Pancreas	Diseased Pancreas: Chronic Pancreatitis	Diseased Pancreas: Acute Pancreatitis	Diseased Pancreas: Carcinoma of Pancreas	Diseased Pancreas: Pancreatic Cyst	Diseased Pancreas: Pressure on or Injury to Pancreas	Jaundice
1	...	25	...	....	....	....	0
2	5.0	...	...	....	....	....	0
3	...	9	...	....	....	....	0
4	...	...	...	1.0	....	....	+
5	...	...	150 (A)	....	....	....	0
6	5 (A)	...	...	....	....	....	+
7	5.5	...	...	....	....	....	0
8	4.5	...	...	....	....	...	+
9	...	2.5	...	....	....	....	0
10	...	...	...	....	....	21	0
11	...	...	...	....	....	12	0
12	...	...	...	10	....	....	+
13	...	...	...	3.1	....	....	+
14	6.2	...	...	....	....	....	0
15	...	...	...	....	15	....	0
16	...	7.8	...	....	....	....	0
17	5 (A)	...	...	....	....	....	+
18	...	60	...	....	....	....	0
19	6.2	...	...	....	....	....	0
20	...	...	...	....	50	....	0
21	4.5	...	...	....	....	....	0
22	5.1 (A)	...	...	....	....	....	+
23	...	9.3	...	....	....	....	0
24	...	...	25	....	....	....	0
25	...	18.0 (A)	...	....	18.0 (A)	18.0	0
26	...	13.6 (A)	...	....	....	....	+
27	5.0 (A)	....	...	....	....	....	+
28	5.2	....	...	....	....	....	0
29	...	3.2	...	....	....	....	0
30	...	....	...	1.5 (A)	....	....	+
31	...	....	...	25.0 (A)	....	....	+
32	...	4.8 (A)	...	....	....	....	+
33	...	....	...	17.5 (A) / 5.0	....	....	+
34	...	....	...	12.5 (A)	....	....	+

* Numerical values represent units of amylase in blood. "A" indicates that autopsy was performed and that the pancreas was examined histologically. In all other cases diagnosis depended on observations at operation.

TABLE 3.—*Cases of Normal Pancreas at Operation or Autopsy*

Case	Age of Patient	Clinical Diagnosis	Blood Amylase, Units	Anatomic Observations
2	42	Chronic cholecystitis.....	5.0	Normal pancreas (operation)
6	62	Carcinoma of the pancreas..	4.5	Carcinoma of biliary tract; normal pancreas (autopsy)
7	47	Pancreatic cyst	5.5	Large metastatic carcinoma of liver (from stomach); normal pancreas (operation)
8	45	Carcinoma of the pancreas..	4.5	Acute hepatitis; normal pancreas (operation)
14	48	Duodenal ulcer.....	6.2	Normal pancreas (operation)
17	53	Carcinoma of the pancreas..	5.0	Acute hepatitis; normal pancreas (autopsy)
19	32	Exstrophy of the bladder; abdominal tumor	6.2	Ovarian cyst; normal pancreas (operation)
21	50	Chronic cholecystitis.....	4.5	Cholecystitis; normal pancreas (operation)
22	48	Stone in the common duct..	5.1	Stone in the common duct; normal pancreas (autopsy)
27	59	Carcinoma of the pancreas..	5.0	Metastatic carcinoma of the biliary ducts and the liver; normal pancreas (autopsy)
28	50	Abdominal tumor.....	5.2	Carcinoma of the gallbladder with metastases to the liver; normal pancreas (operation)

suspected on admission, but hepatitis was indicated by later events. In table 4 is summarized the data for ten cases of chronic pancreatitis. In only two of these cases did we have an opportunity to make histologic examination. The remaining ones are adequately described in the clinical abstracts; that is, seven cases of carcinoma of the pancreas, two of pancreatic cysts, two of acute pancreatitis, and one each of pressure and of injury to the pancreas. At autopsy in the last-named case, a beginning pancreatic cyst was found at the probable site of the injury; this illustrates the pathogenesis of the condition.

REPORT OF CASES

The pancreas in all but two cases (nos. 35 and 36) was examined at operation or at autopsy. The liver function test referred to is that of Graham and Cole.[32]

TABLE 4.—*Cases of Chronic Pancreatitis*

Case	Age of Patient	Clinical Diagnosis	Blood Amylase, Units	Operative Observations
1	50	Chronic cholecystitis.....	10.8 25.0	Thickened, hard pancreas
3	35	Chronic cholecystitis.....	9.3	Enlarged, firm pancreas
9	34	Chronic cholecystitis.....	2.5	Enlarged pancreas
10	52	Duodenal ulcer.....	25.0	Indurated ulcer perforating into the pancreas
16	33	Chronic cholecystitis.....	7.8	Hard indurated pancreas
18	62	Chronic cholecystitis.....	60.0	Markedly enlarged and firm pancreas
23	34	Chronic cholecystitis.....	9.4	Stony, hard pancreas
26	56	Carcinoma of the pancreas	13.6	Interacinar infiltration and recent acute inflammation (autopsy)
29	24	Chronic cholecystitis.....	3.0	Stony hard pancreas (operation)
32	57	Carcinoma of the pancreas	4.8	Extensive fibrosis of the pancreas (autopsy)

CASE 1.—In H. F., a laborer, aged 50, admitted to the hospital on Oct. 18, 1927, the onset of the condition occurred three years before with epigastric pain after meals, often persisting until the next meal. One week before admission, jaundice appeared, becoming steadily worse.

Examination showed severe jaundice but no evidence of severe pain. The van den Bergh test on admission showed 90 mg. per hundred cubic centimeters. The urine contained bile. The stool was watery and showed some free fat with sudan III stain.

By October 22, the jaundice had cleared considerably. The urine still contained bile.

On October 24, an intravenous cholecystogram showed a faint shadow. The test for liver function showed 40 per cent retention at thirty minutes; the blood amylase value was 10.8 units.

On November 2, the jaundice was nearly gone. The urine showed no bile. Blood amylase amounted to 25 units.

On November 9, an operation was performed. The gallbladder was greatly thickened and gray. The liver was enlarged; no stones were felt in the common

32. Graham, E. A.; Cole, W. H.; Copher, G. H., and Moore, S.: Diseases of the Gallbladder and Bile Ducts, Philadelphia, Lea & Febiger, 1928.

duct, but there were many greatly enlarged glands along it. The head of the pancreas was definitely thickened and firm. The gallbladder was removed. The common duct was opened and drained. The patient vomited repeatedly after the operation. Gastric lavage yielded 1,100 cc. of fluid at one time. Death occurred two days after operation; no autopsy was performed.

CASE 2.—E. L. B., a housewife, aged 42, admitted to the hospital on Feb. 14, 1928, had had several courses of antisyphilitic treatment, several years before; the Wassermann reaction was now plus or minus. The onset of the present illness occurred three weeks before admission, with vague dyspepsia. Several days later there was pain in the right upper quadrant of the abdomen with some nausea and vomiting, which continued mildly for a week. The onset of jaundice occurred two weeks before admission; the stools became clay-colored and soft, and the patient had complete anorexia.

Examination showed intense jaundice and tenderness in the right upper quadrant, especially over the gallbladder. The edge of the liver was felt. The test for liver function showed 80 per cent retention. Blood amylase on admission was 0; that is, no diastatic activity could be demonstrated. The van den Bergh reaction on admission was 44 mg. per hundred cubic centimeters. Three weeks later when the jaundice had disappeared, the blood amylase was normal (5.4 units); the van den Bergh reaction was 10 mg. per hundred cubic centimeters, and the result of the liver function test 8 per cent retention. In a cholecystogram there was nonvisualization of the gallbladder.

At operation on March 21, the gallbladder was seen to be slightly thickened, adherent and enlarged. The sentinel gland was three times the normal size, as were the cystic and common ducts. The liver and spleen were adherent to the parietal peritoneum. The pancreas seemed to be normal on palpation. The gallbladder was removed; it contained light brown bile. The patient was discharged on April 16.

CASE 3.—In P. F. K., a housewife, aged 35, admitted to the hospital on Dec. 3, 1928, the onset occurred four or five years before with attacks of severe epigastric pain radiating to the right upper quadrant of the abdomen. A vague pain in the epigastrium was relieved by sodium bicarbonate. The patient lost 60 pounds (27.2 Kg.) in weight in four years. She had had five attacks in the past nine months. There had been no jaundice, but the stools had been clay-colored. Now, for the first time, there was jaundice. Examination showed: jaundice, muscle guard and tenderness in the right upper quadrant under the margin of the ribs. In three weeks, the jaundice was nearly gone, the appetite was better and the pain was absent. The blood amylase value was 9.3 units. The test for liver function showed 22 per cent retention. An operation was performed on Jan. 16, 1929. The gallbladder, on removal, was a thick pinkish gray. Four faceted stones were removed from the common duct which was drained. The pancreas was firm and slightly enlarged. The patient was discharged on February 1.

CASE 4.—In W. C., a policeman, aged 46, admitted to the hospital on Sept. 7, 1927, the condition began two months before with jaundice varying in intensity. One year before admission, while in the hospital for a minor injury, the patient was found to have glycosuria and had been on a diet since. There was slight pain in the right upper quadrant of the abdomen. He had had from ten to sixteen loose stools a day for the past three weeks, and had lost 35 pounds (16.3 Kg.) in weight.

Examination showed a well developed man who was deeply jaundiced. Blood sugar was 146 mg. and serum bilirubin 86.1 mg. per hundred cubic centimeters; the blood amylase value was 1 unit. The test for liver function showed 25 per cent retention.

An operation was performed on September 21. The gallbladder contained 500 cc. of tarry bile. There was a large mass at the head of the pancreas, and small metastases to the liver. A cholecystogastrostomy was performed. The stools contained bile four days after the operation. Recovery was good, and the patient was discharged on October 5.

CASE 5.—In E. M. C., a housewife, aged 67, admitted to the hospital on Dec. 31, 1927, the onset occurred eighteen hours before entrance to the hospital, which was two hours after a large meal; there was severe pain across the upper part of the abdomen and constant vomiting. Morphia had little effect and the patient grew weaker. On entrance, she was pulseless; the temperature was 38.8 C. (101.8 F.), and the white blood cells numbered 4,000. The upper part of the abdomen was rigid and painful. The patient was treated for shock. The blood amylase value was 150 units. The patient grew worse, and died in about six hours. A past history of hypertension and a mild cerebral accident one year before was obtained. The clinical diagnosis rested between coronary thromboses and an abdominal accident although acute pancreatitis was suspected. Autopsy showed acute pancreatitis with fat necrosis confined to the pancreas, acute peritonitis and gallstones.

CASE 6.—R. C., a laborer, aged 62, admitted to the hospital on April 4, 1928, developed pain in the lumbar region three months before. Jaundice appeared two months before admission. With the increase of jaundice, pain diminished and soon disappeared. There was a loss of 25 pounds (11.3 Kg.) in weight. There was no dyspepsia; intense itching was present, but no diarrhea. The blood amylase value was 4.8 units. The test for liver function showed 17 per cent retention.

At operation, several nodules were found along the common duct. The pancreas seemed to be hard. One month later, the patient died. Autopsy showed a normal pancreas and carcinoma of the gallbladder with metastases to the liver and to the glands along the common duct.

CASE 7.—In G. J. W., a farmer, aged 47, admitted to the hospital on March 31, 1928, the onset occurred two months before with dyspnea on exertion; there was no edema. Examination showed: red blood cells, 3,800,000; hemoglobin, 40 per cent; differential count, normal; blood pressure, 120 systolic and 70 diastolic. A tumor was seen and felt in the right upper quadrant of the abdomen; it was probably in the liver; the latter was hard, and its right border was felt distinctly. The guaiac test of the stool repeatedly gave positive results; there was no fat. The heart was normal; an electrocardiogram was negative. A series of gastro-intestinal x-ray pictures revealed an extra-alimentary tumor, independent of the gastro-intestinal tract, which suggested a pancreatic cyst. There was a normal amount of blood amylase (5.5 units). The test for liver function showed 17 per cent retention (normal). On April 14 an operation was performed disclosing a tumor in the liver the size of a grapefruit; it was soft but not fluctuant. There was a mass in the lower third of the greater curvature of the stomach. The lymph glands and a piece of the tumor were removed. The diagnosis was medullary carcinoma of the stomach with metastases to the liver. The patient was discharged on May 1.

CASE 8.—F. L. B., a laborer, aged 45, admitted to the hospital on Oct. 26, 1928, complained of fatigue and anorexia three weeks before. Two weeks before admission, he became yellow. He felt no pain. Examination showed deep jaun-

dice; the edge of the liver was felt below the costal margin. The serum bilirubin was 49 mg. The clinical diagnosis was carcinoma of the pancreas.

The stool was light brown, and acid when tested with litmus. The patient was afebrile during the entire illness. The white blood cells numbered 10,000; the lymphocytes, 37 per cent. Blood amylase amounted to 6.5 units. The tests for liver function showed high retention (80 per cent).

At operation, on November 7, the pancreas proved to be soft and normal in size with a small hard nodule in its head, which did not cause obstruction (retroperitoneal lymph mode?). The liver was swollen. The common duct was not dilated. The gallbladder was moderately distended. A piece of liver which was removed showed acute hepatitis. The patient was discharged on Jan. 28, 1929, well.

CASE 9.—C. J. S., a clerk, aged 34, admitted to the hospital on Oct. 29, 1928, said that she was awakened at 4 a. m., six months before, with pain in the left infracostal region. Chills and night sweats had occurred for six weeks. At the time of admission, she had intermittent infracostal pain on the left side, often lasting for ten days at a time. The patient had a low grade fever, her temperature varying from 99.4 to 100 F. A series of gastro-intestinal x-ray pictures were negative. In the sugar tolerance test, a peculiar rise occurred in two hours. The gallbladder was faintly visualized and showed torsion. Blood amylase amounted to 2.5 units two months before admission; another examination after entrance to the hospital gave the same result.

At operation, on November 15, a chronic inflammation of the gallbladder and appendix was found. The pancreas was definitely enlarged, especially in its body, but it was not very hard (lipomatosis of the pancreas?). The patient was discharged on November 30.

CASE 10.—G. H. B., a mechanic, aged 52, gave a meager history of gradually increasing vomiting for the previous six months. Two weeks before admission, roentgen examination showed marked six-hour retention and a long narrow duodenal cap. On admission, the patient was drowsy and weak. The nonprotein nitrogen amounted to 166 mg. per hundred cubic centimeters, and the secretion of phenolsulphonphthalein was 5 per cent in two hours. Blood amylase amounted to 21 units. Fluids administered parenterally, and high caloric liquid feedings were given; in fourteen days, the nonprotein nitrogen and the phenolsulphonphthalein were normal, and the general condition was markedly improved. Blood amylase showed 21 units. At operation, a large duodenal ulcer adherent to and perforating into the pancreas was found.

CASE 11.—J. A. H., aged 61, admitted to the hospital on March 21, 1928, had a huge hydronephrosis of the right kidney. No gallbladder shadow was visible. Blood amylase amounted to 12.5 units. A right nephrectomy was performed on April 2. A large dilated sac was observed to press on the gallbladder and the pancreas. The patient was discharged on April 19.

CASE 12.—J. W. S., aged 58, admitted to the hospital on Feb. 29, 1928, developed nausea and general abdominal discomfort eight weeks before admission; he became worse, and in one week his color was yellow. He had had diarrhea for several weeks. One attack of transient pain had been felt in the upper right quadrant of the abdomen. The Wassermann reaction was negative. On three examinations with sudan III stain, the stool showed fat; no bile was found. Sugar was repeatedly shown in the urine from March 1 to 15; it then disappeared. Blood sugar amounted to 116 mg. per hundred cubic centimeters, blood amylase to 10.7 units. The test for liver function showed 23 per cent retention.

At operation, a hard mass was found in the head of the pancreas, and a cholecystogastrostomy was performed. There was no bile in the stool on discharge, March 27, although the jaundice had cleared up considerably.

Case 13.—P. J. S., a foreman, aged 37, first admitted to the hospital on Nov. 4, 1926, gave a history of intermittent and irregular attacks of jaundice for one year, with a loss of 35 pounds (16.3 Kg.) in weight and from five to six stools a day. Examination showed an enlarged liver and jaundice. The test for liver function yielded 17 per cent retention. The clinical diagnosis was cirrhosis of the liver. An operation was advised but was refused by the patient. The patient was discharged on November 12, but was readmitted on July 6, 1927. Intermittent attacks of jaundice had continued, with greater severity. The test for liver function showed 17 per cent retention. Blood amylase amounted to 3.1 units. An operation on July 10 revealed a large tumor in the head of the pancreas. The patient died on July 15.

Case 14.—In R. M., the blood amylase amounted to 6.2 units. An operation was performed for duodenal ulcer. A gastro-enterostomy was also performed. The pancreas was of normal appearance and consistency. Recovery was uneventful.

Case 15.—R. G., a colored laborer, aged 46, was admitted on April 13, 1927, with a history of pain around the umbilicus after meals for the previous one and a half years. The patient had lost 35 pounds (16.3 Kg.) in weight. Examination showed a tumor in the upper part of the abdomen, that was cystic, rounded and movable. A series of gastro-intestinal x-ray pictures showed an extra-alimentary tumor. Blood amylase amounted to 14.7 units. An operation was performed on April 25. A large pancreatic cyst was marsupialized. The fluid contained 300 units of amylase per cubic centimeter. The blood amylase value, three days after the operation, was 6.7 units. The wound healed rapidly, and the patient was discharged on May 7. He was readmitted on October 7 with a history of excellent health until the onset of pain, nausea and vomiting two weeks before. Examination showed evidence of chronic cholecystitis. An operation was performed on November 11. The gallbladder and stones were removed. The pancreas was difficult to palpate but the head seemed to be somewhat indurated.

Case 16.—G. S., a housewife, aged 33, admitted to the hospital on March 28, 1928, gave a history of severe, nearly painless jaundice, occurring seven years before and lasting for eight months. She had had intermittent attacks of jaundice of short duration for the past few years, and attacks of pain requiring morphine. Examination showed tenderness to the right of the umbilicus and over both twelfth ribs. The blood amylase amounted to 7.8 units. The test for liver function showed 9 per cent retention (normal). At operation, on April 16, no gallbladder and no stones were found. The common duct was drained; the pancreas was hard and indurated. The patient was discharged on April 21.

Case 17.—H. F., a housewife, aged 53 (referred by Dr. A. Goldman), gave a history of diabetes of three years' duration, controlled by diet without insulin. The onset of the present illness occurred one month before admission to the hospital, with chills and fever which subsided in ten days. Ten days later jaundice was noted, becoming increasingly severe. Fever returned and rose as high as 104 F. There was vomiting, and pain in the joints, but no abdominal pain. Examination showed deep jaundice, a large mass in the right upper quadrant of the abdomen, probably in the liver, which was hard but not tender. The urine contained bile but no urobilin. The test for liver function showed 75 per cent retention. The clinical diagnosis was stone in the common duct, or carcinoma of the pancreas. The blood amylase amounted to 5 units. An operation revealed

a normal pancreas, an enlarged liver, and a normal gallbladder and ducts. At the neck of the gallbladder, numerous enlarged glands were found which were removed. The patient died five days later. At autopsy, acute degenerative hepatitis and nephritis were found. The pancreas was normal.

CASE 18.—H. W. B., a housewife, aged 62 (referred by Dr. W. F. Peterson), gave a history of low grade colitis for eighteen years; and attacks of pain in the epigastrium, vomiting and clay-colored stools at intervals for the past year. Examination showed only a little albumin and hypertensive myocarditis; a cholecystogram showed no shadow. The blood amylase amounted to 60 units. An operation, performed on Oct. 15, 1928, showed evidence of an ulcer near the pylorus. A posterior gastro-enterostomy was performed; the appendix was removed and the gallbladder was emptied of many stones and drained. The pancreas was markedly enlarged and firm. The course was uneventful until eight days after operation when the patient suddenly died. No autopsy was performed.

CASE 19.—T. J. J., a housewife, aged 32, was admitted to the hospital on Feb. 16, 1929, for the cure of an exstrophy of the bladder which she had had since birth. A large abdominal tumor was found during the routine examination; it was freely movable but firm and indefinitely outlined. Roentgen examination showed an extra-alimentary tumor. A pancreatic cyst was suspected. The blood amylase amounted to 6.2 units. At operation, on March 4, the tumor was found to be a huge, bilateral ovarian cyst. The pancreas was normal. The patient was discharged on March 20.

CASE 20.—M. E. F., a housewife, aged 44, admitted to the hospital on Oct. 28, 1927, gave a history of irregular attacks of pain in the epigastrium for the past ten years, with nausea, belching and vomiting. An abdominal swelling observed four weeks before admission increased in size. Examination showed a huge, tense, cystic tumor in the epigastrium. The blood amylase amounted to 29 units on October 28, and 50 units on November 2. A series of gastro-intestinal x-ray pictures revealed an extra-alimentary tumor, probably a pancreatic cyst. At operation, on November 4, the large cyst was drained of 2,000 cc. of fluid; a large piece of necrotic tissue was removed and the cyst was marsupialized. The cystic fluid contained 1,200 units of amylase. No bile or trypsin was demonstrable. The wound healed slowly but satisfactorily. Recovery was uneventful, except for persistent tachycardia and weakness (pancreatic asthenia?). On November 9, blood amylase amounted to 10 units. The patient was discharged on December 3.

CASE 21.—M. S. Y., a housewife, aged 50, was admitted to the hospital on Jan. 9, 1928. The onset occurred fifteen months before admission, with dyspepsia and cramping pain in the epigastrium. Since then, the patient had lost 50 pounds (22.6 Kg.). Results of an examination were negative. A cholecystogram revealed no shadow. A series of gastro-intestinal x-ray pictures were negative. Blood amylase amounted to 4.5 units. In an operation, on Jan. 12, 1928, a diseased gallbladder and a number of stones were removed. The pancreas felt normal. The patient was discharged on January 27.

CASE 22.—C. L. H., a laundress, aged 48, admitted to the hospital on July 14, 1927, gave a history characteristic of disease of the gallbladder. Examination showed jaundice and an enlarged, tender liver. The test for liver function showed high retention of dye (80 per cent). Blood amylase amounted to 5.1 units. An operation, on July 19, revealed a stone in the cystic duct and several stones in the common duct, which were removed. White bile was found above the obstruction. A cholecystectomy was performed; the pancreas was normal. Death occurred in twelve hours. Autopsy revealed 1,400 cc. of blood in the peritoneal

cavity, chronic hepatitis and pulmonary edema. The pancreas was normal grossly, and in section showed only a slight increase in interacinar connective tissue.

Case 23.—In A. A. L., a housewife, aged 34, admitted on Jan. 24, 1929, the history and examination disclosed symptoms characteristic of chronic disease of the gallbladder. Blood amylase amounted to 9.4 units. At operation, on February 1, the gallbladder and several stones were removed. The pancreas was as stony hard as if it were affected with carcinoma. The patient was discharged on February 15.

Case 24.—W. H., a laborer, aged 42, admitted to the City Hospital on Nov. 28, 1927, had experienced sudden pain to the right of the umbilicus two days before; it became worse, and the patient vomited persistently. The abdomen was scaphoid; there was rigidity in its upper portion. The white blood cells numbered 17,400. Generalized pain was present. At operation, free blood was found in the peritoneal cavity; there were many flecks of fat necrosis in the omentum. The pancreas was enlarged and hemorrhagic. The lesser peritoneal cavity was drained, and the patient developed signs of tetanus and died on December 5. Blood amylase, two days after operation, amounted to 25 units.

Case 25.—G. K., a clerk, aged 21, was admitted to the City Hospital on Dec. 4, 1928, as an emergency case with a history of severe pain in the epigastrium and of persistent vomiting for forty-eight hours. Six months before, he was in an automobile accident and sustained a crushing blow in the upper part of the abdomen following which he vomited persistently. Operation revealed a large mass, probably a hematoma, in the region of the pancreas. Blood amylase a few weeks later amounted to 16.6 units. The patient was discharged as improved, but had attacks of pain and vomited at irregular intervals, once vomiting blood. Blood amylase, on November 1, amounted to 16.8 units.

On this admission he presented the picture of an acute abdominal condition. His abdomen was distended and rigid, especially in the upper half, and was exquisitely tender to pressure. The temperature was 102 F., the pulse rate 130. The white blood cells numbered 14,000, later 42,000. In view of the previous history, acute pancreatitis was suspected. Blood amylase, however, was but 7.1 units. At operation the mass noted at the first operation was found; the omentum around it showed one large whitish area of old, organizing fat necrosis. No other fresh areas of fat necrosis were seen. The peritoneal cavity contained about 2 liters of clear straw-colored fluid. The loops of small intestine were distended, but no peritonitis was present. The mass was incised and found to be solid fibrous inflammatory tissue in which several loops of collapsed small bowel were seen. Further exploration revealed no evidence of abscess or softening. The general condition of the patient precluded further work, and an enterostomy was performed with a rubber tube; the wound was closed with through-and-through ligatures. After a stormy convalescence, the patient recovered and gained 30 pounds (13.6 Kg.) in weight. Four months later, he became suddenly ill and died in a week with generalized petechiae. Autopsy revealed a vegetative endocarditis. The pancreas was small and hard, and there was a cyst at the head, about 5 cm. in diameter, containing clear fluid. Section of the gland showed advanced cirrhotic changes. Blood amylase, one week before death, amounted to 18.5 units.

Case 26.—In M. F., a housewife, aged 56, admitted to the City Hospital on Dec. 28, 1928, the onset occurred two weeks before admission, with nausea, anorexia, dyspepsia and increasing jaundice. There was a loss of 25 pounds (11.3 Kg.) in weight. Examination showed a sick woman, with jaundice, who was fairly well nourished and had many petechiae. A series of gastro-intestinal x-ray pictures

showed nothing abnormal. Blood amylase amounted to 13.7 units. A test of liver function showed 15 per cent retention. The Wassermann reaction was negative. The phenolsulphonphthalein test gave normal results. Death occurred suddenly on Jan. 19, 1929. The clinical diagnosis was carcinoma of the pancreas. A limited autopsy revealed no carcinoma. The pancreas showed old interacinar fibrosis with a recent acute inflammatory process.

CASE 27.—In F. F., a laborer, aged 59, admitted to the City Hospital on Jan. 18, 1929, the onset occurred two months before admission, with pain in the chest and the upper part of the abdomen, and with increasing jaundice. Examination showed a deeply jaundiced patient with an irregular mass in the right upper quadrant of the abdomen, probably in the liver. A series of gastro-intestinal x-ray pictures were negative. Blood amylase amounted to 5 units. Operation showed multiple nodules in the liver, and a mass in the region of the head of the pancreas. The patient died several days later. Autopsy showed that the mass felt at operation was a large retroperitoneal node, and was not connected with the pancreas. Sections of the pancreas showed normally formed acini with no sign of obstruction of the ducts. There were numerous nodules along the common duct and in the liver to account for the jaundice. Sections showed the tumor to be of the neuroganglionic type, probably arising from retroperitoneal nerve tissue.

CASE 28.—F. M. M., a housewife, aged 59, admitted to the hospital on Jan. 15, 1929, gave a history of weakness for the past year, enlargement of the epigastrium and discoloration of the skin. Examination revealed a prominent abdomen, a hard, nodular, enlarged liver and an enlarged spleen. All laboratory tests gave negative results. Biopsy of the skin showed no iron pigment. The liver function test showed normal retention (18 per cent). Blood amylase amounted to 5.2 units. A series of gastro-intestinal x-ray pictures were negative. A cholecystogram did not give visualization. At operation, under local anesthesia, on January 28, the liver was found to be tremendously enlarged and to contain multiple metastases. The gallbladder was edematous and contained stones. The stomach could not be examined well on account of pain. The pancreas felt normal. Biopsy showed adenocarcinoma, probably from the gallbladder. The patient was discharged on February 21.

CASE 29.—C. M., a housewife, aged 24, admitted to the City Hospital on Feb. 14, 1928, gave a history of intermittent attacks of severe pain in the right upper quadrant of the abdomen, with vomiting. Examination showed an obese woman, slightly jaundiced, with tenderness over the entire abdomen, especially in the right upper quadrant. Blood amylase amounted to 3.1 units. A cholecystogram showed a faint shadow. At operation, on February 27, a diseased gallbladder and several stones were removed. There was no stone in the common duct. The probe was passed into the duodenum from the opening in the duct. The pancreas was hard throughout its entire extent, and felt like carcinoma.

CASE 30.—In J. S. (referred by Dr. John Hotz), a laborer, aged 56, admitted to the City Hospital on Feb. 1, 1929, the onset occurred six months before admission, with gradually increasing, painless jaundice. The patient had diarrhea "severe enough to take medicine for it." Five weeks before admission, swelling of the ankles was noted. Three weeks later there was swelling of the abdomen and dyspnea. Examination showed a distended abdomen. Paracentesis on numerous occasions yielded from 5,000 to 6,000 cc. each time. A series of gastro-intestinal x-ray pictures were negative. Blood amylase amounted to 1.1 units. The Wassermann reaction was negative. Jaundice grew progressively more intense. Death occurred two months after admission. A limited autopsy revealed a hard mass at

the head of the pancreas. Microscopic examination showed vacuolization and atrophy of the acini.

CASE 31.—M. B. M., a man 48 years of age, admitted on March 22, 1929, gave a history of treatment for syphilis; the Wassermann reaction was now negative. The onset occurred six weeks before admission, with severe diarrhea. Two weeks later the gradually increasing jaundice began; there was no pain. Examination revealed extreme icterus, some rigidity and tenderness in the epigastrium; edema of the lower part of the legs, and ascites. The test for liver function showed 18 per cent retention (normal). In two examinations, blood amylase amounted to 25 and 30 units, respectively. At operation, on April 12, 3 liters of ascitic fluid was removed; an enlarged gallbladder and hobnail liver were observed. An omentopexy was performed. Death occurred three days later. Autopsy revealed hepatic cirrhosis, and carcinoma at the orifice of the common and pancreatic ducts, obstructing both. The pancreas on section showed pink-staining acini, tremendously dilated ducts and early hemorrhagic pancreatitis.

CASE 32.—In W. H. W., a laborer, aged 57, admitted to the hospital on March 19, 1928, the onset of the condition occurred seven weeks before admission, with a progressive increase in jaundice and dull pains in the lower portion of the chest and back, gradually becoming more severe. Constipation was marked. Examination showed marked jaundice and a large tumor in the right upper quadrant of the abdomen, probably the liver, which was nodular and extended down into the umbilicus. The Wassermann reaction was four plus. The test for liver function showed 17 per cent retention. Blood amylase amounted to 4.8 units. A series of gastro-intestinal x-ray pictures showed an extra-alimentary tumor, and hydrops of the gallbladder (?). The patient was discharged on March 28. Death occurred on May 9. An autopsy, performed by Dr. D. L. Harris, showed an enormously dilated gallbladder, and a nodular, hard, fibrotic pancreas which constricted the lower end of the common duct with a fibrous band. Section of the gland showed no carcinoma; there was only an extensive fibrosis with scattered groups of acinar cells.

CASE 33.—In W. J., a colored laborer, aged 57, admitted to the hospital on March 12, 1929, the onset of the condition occurred six weeks before admission, with pain in the epigastrium, increasing jaundice, and constipation. There was a loss of 100 pounds (45.3 Kg.) in weight during this time from a usual weight of 220 pounds (99.8 Kg.). Examination showed intense jaundice, glycosuria, and 220 mg. of blood sugar per hundred cubic centimeters, a condition that was soon controlled with diet and insulin. The abdomen was soft; there was a tumor in the epigastrium, probably in the gallbladder. Blood amylase, on March 15, amounted to 7.5 units; on April 5, 5 units. At operation, on April 12, a tumor was felt in the head of the pancreas; an enlarged gallbladder was anastomosed to the stomach. Death occurred three days later. The autopsy showed a carcinoma in the head of the pancreas through which the pancreatic duct could be followed from the tail to the duodenum without apparent obstruction. The tumor, however, occluded the lower common duct. Section of the body of the pancreas showed extensive fibrosis of the gland with many normal-staining acinar cells.

CASE 34.—In C. D., a colored laborer, aged 49, admitted to the hospital on March 27, 1929, the onset occurred two months before admission, with dull pain in the epigastrium, bloating constipation, increasing jaundice and the loss of 60 pounds (27.2 Kg.) in weight. On examination the liver edge was felt. Other observations were: a distended gallbladder (?), deep icterus, glycosuria, a Wassermann reaction of four plus, blood sugar 216 mg. per hundred cubic centimeters, and

an icteric index of 150. The stool showed fatty acid. A series of gastro-intestinal x-ray pictures revealed a retroperitoneal tumor. Blood amylase, on April 1, amounted to 12.5 units; on April 16, 10.8 units. On May 8 the patient died suddenly. Autopsy showed a large tumor in the head of the pancreas compressing the common bile duct and the main pancreatic duct; the latter was dilated to the size of a finger. Section of the tail of the pancreas showed many normal-staining acini, and general dilatation of the small ducts.

CASE 35.—M. M., a housewife, aged 48, admitted to the hospital on Oct. 23, 1928, developed jaundice one month before admission, which gradually increased. She lost 33 pounds (14.9 Kg.) in weight. There had been pain along the costal margin for six months, vomiting for one week. Examination showed a blood sugar of 0.294 Gm. per hundred cubic centimeters. The gastric contents after a test meal were 63 degrees total acid. The serum bilirubin on admission was 21; two days later, 40; three days later, 83, and three days later, 65. Blood amylase, on October 31, amounted to 1.9 units and on November 2 to 1.8 units. The patient died suddenly on November 19. No autopsy was performed.

CASE 36.—A. G. A., a housewife, aged 36, was admitted on Oct. 30, 1928, as an acute emergency case with a history of vomiting daily for the previous two weeks. There had been pain in the epigastrium, loss of weight, and a temperature of from 101 to 103 F. Examination showed an acutely ill woman with jaundice and much spasm in the epigastrium and right upper quadrant of the abdomen. An indefinite mass in the epigastrium was not outlined because of muscle spasm. The condition was thought to be of pancreatic origin, but the blood amylase was normal (4.3 units). A series of gastro-intestinal x-ray pictures were negative. The jaundice and fever cleared, and a history of alcoholism was then obtained. The diagnosis was hepatitis in alcoholic psychosis. The patient was discharged on December 18.

COMMENT

The immediate inference to be drawn from the data herein presented is that there is a definite correlation between the concentration of blood amylase and the presence or absence of disease in the pancreas, thus bearing out the experimental evidence that this ferment in the blood is largely of pancreatic origin. The main application of our data, however, concerns the addition of a valuable aid in the diagnosis of diseases of the pancreas which are frequently difficult of clinical detection.

A brief summary of our observations is as follows: In thirty-six patients, the blood amylase was found to lie between 4.3 and 6.8 units. In eleven of these, the pancreas was either felt at operation or examined microscopically after autopsy and found to be normal (table 3). The remaining twenty-five were patients convalescent from a variety of conditions (table 1). In twenty-two patients, abnormal concentration of blood amylase was found; in fifteen of them increased values ranging from 7.8 to 150 units but in seven cases values below normal, that is, from 0.5 to 3 units. In twenty-one of these twenty-two cases which showed abnormal values, disease of the pancreas was found, either at operation or at autopsy, distributed among the conditions as follows: chronic pancreatitis ten cases (table 4), carcinoma of the pancreas

seven, acute pancreatitis two, pancreatic cyst two, injury to the pancreas one, and pressure on the pancreas one. All cases in which an operation or an autopsy was performed are summarized in table 2.

Certain limitations of these observations must be noted. Our basis for diagnosis of disease in the pancreas in the majority of the cases was dependent on the data obtained at operation. The reliability of palpation or even of inspection of this small inaccessible organ during laparotomy may be questioned seriously. The liver, large and visible as it is, was for a long time overlooked as the site of inflammatory changes. It was only after the extensive observations [32] in this clinic, that the frequency of hepatitis was established and its importance first realized. But much of the evidence rested on the microscopic examination of tiny pieces of liver removed at operation. It is, of course, more difficult to perform biopsy on the pancreas. J. H. Nicoll,[33] however, a British surgeon, described a number of cases in which he has excised a wedge of tissue from the pancreas through an opening in the gastrocolic omentum and was enabled, thereby, to make a diagnosis of pancreatitis from the microscopic examination of the tissue removed in seven cases in which the clinical diagnosis was entirely different. He pointed out also the possible unreliability of a palpatory diagnosis of pancreatic disease at operation. In one case of our series (no. 27), autopsy showed that a mass in the region of the head of the pancreas, felt at operation and diagnosed as a carcinoma at the head of the pancreas, was in reality an enlarged retroperitoneal lymph gland, and that the pancreas was normal microscopically. In twelve cases of our series we obtained microscopic examinations of the pancreas (nos. 5, 6, 17, 22, 25, 26, 27, 30, 31, 32, 33 and 34 which came to autopsy). It is significant that in ten of them there was a complete confirmation of the observations on blood amylase. The other two (cases 32 and 33) will be discussed later.

A possible limitation in the method described lies in the making up of the starch suspension, since different preparations give solutions of different viscosities and varying rates of hydrolysis. By using the same batch of starch and by making a fresh preparation of it each time in the same way, uniform results were obtained. In our experience, the method was accurate to within 10 per cent in repeated determinations on the same specimen. We are now working on methods for preparing a more standard and more simple solution of starch.

The existence of jaundice, per se, has no effect on the amylolytic activity of blood. This was determined by actually adding bile to normal serum and finding no alteration in its diastatic power. Moreover, in five cases of hepatogenous icterus in which the pancreas was not

33. Nicoll, J. H.: Brit. M. J. **2**:625, 1919.

affected, "normal" amylase values were obtained (table 3, nos. 6, 8, 17, 22 and 27). This fact has enabled us to exclude the pancreas in a number of cases of painless jaundice when the clinical diagnosis pointed to carcinoma of the pancreas.

In a number of cases, too, the amylase determination gave the only indication of pancreatic disease, the clinical evidence being either inconclusive or indicative of another diagnosis (nos. 5, 13 and 15). In one case a normal amylase value ruled out a possible pancreatitis and subsequent events showed the inference to be correct (case 36). In another instance (no. 7) an abdominal tumor, supposed from roentgen examination to be a pancreatic cyst (blood amylase normal), was found at operation to be a large metastatic nodule from a carcinoma of the stomach.

The significance of the low amylase values obtained in this series of cases can easily be surmised. From the experimental evidence already mentioned one might interpret it as an indication of more or less complete atrophy of the acinar cells, for if the amylase of the blood is derived from these cells, atrophy would probably bring about this decrease. In only one case with a low value (no. 30) did we have an opportunity of examining the pancreas microscopically. In this case of carcinoma of the pancreas the blood amylase value, two weeks before death, was only 1.5 units or from about one-third to one-fourth the normal value. On section, this pancreas showed extensive involvement of the acini many of which were replaced by fat cells, the others being necrotic or completely fibrosed. The islets of Langerhans appeared normal. Of the other six cases of decreased amylase concentration, four (nos. 4, 9, 13 and 29) showed changes at laparotomy. The fifth patient (no. 35) had both glycosuria and jaundice, but died; no autopsy was obtained. The last case (no. 2) is more difficult to explain. On admission the patient had almost no amylolytic activity in the blood and showed intense jaundice. Operation was performed five weeks later, after the jaundice had disappeared. At this time the blood amylase was normal. The laparotomy revealed chronic hepatitis and what was taken to be a normal pancreas. It perhaps illustrates the rapid power of the pancreas to recover from a severe degree of inflammation.

The significance of the increased amylase in the blood seems clear. Obstruction to the ducts leading to increased absorption of pent-up ferments into the blood finds experimental corroboration in the evidence already cited. This is probably the mechanism in the cases of obstruction due to carcinoma (as well shown in no. 31) unless the process has led to atrophy of the acini. Atrophy probably occurred in three of our seven cases and accounts for the low amylase value in them. In a pancreatic cyst there is either pressure on the gland leading to a generalized occlusion of the ducts or an increased absorption of ferments from the

lining of the cyst; for the fluid in the cyst in our two cases contained 300 and 1,200 units of amylase or from sixty to 250 times the concentration in normal blood. The inflammatory process in chronic pancreatitis probably leads to obstruction of the smaller ducts by scar tissue. Interlobular and interacinar fibrosis of this kind has been described by Opie [34] and others. Experimentally we have observed this same histologic change in the pancreas of dogs intubated for the collection of pancreatic juice [35] whenever the secretion became infected. Although no obstruction could be found at autopsy, the flow of pancreatic juice diminished markedly and an increase in the blood amylase was demonstrable in each case. If, however, the fibrosis progresses to completion so that all the acini are replaced with fibrous tissue, one would expect a diminution in the blood amylase. This is probably the explanation of the low value in case 29. In certain cases, pancreatic acini may become replaced by fat, the so-called lipomatosis of the pancreas as described by Balo and Ballon.[36] In this event a similar lowering of the ferment in the blood might occur, thus explaining the enlarged soft pancreas in case 9. Only by histologic examination, however, could such a correlation be really established. In acute pancreatitis there is an abnormal absorption of ferments into the blood because of acute inflammatory changes and tryptic digestion of the walls of the ducts, so that the secretion instead of flowing on into the duodenum makes its way into the surrounding tissues and into the blood and lymphatics.

Disease of the pancreas may thus affect the concentration of blood amylase in two opposite directions: By obstruction of the outflow of pancreatic juice, there is an increased resorption of ferments into the blood; by atrophy of the acini there is a lowering of the normal resorption due to a lowered ferment production. In the former case the blood amylase is high, in the latter low. In a case of progressive obstruction leading to atrophy it is easy to see that a point would be reached when the blood amylase would be neither high nor low; that is, it would be "normal." A mechanism of this kind probably explains the normal observations on blood amylase in cases 32 and 33 in which marked disease of the pancreas was found at autopsy. In case 33 the first determination was slightly elevated (7.5 units); a second one three weeks later was normal (5). It is probable that had the patient lived, the amylase value would have become subnormal, since on section the gland appeared to be well on the way to atrophy. In case 32 our only determination was made two months before death.

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34. Opie, E. L.: Diseases of the Pancreas, Philadelphia, J. B. Lippincott Company, 1911.

35. Elman, R., and McCaughan, J. M.: J. Exper. Med. **45**:561, 1927.

36. Balo, J., and Ballon, H. C.: Surg. Gynec. Obst. **48**:1, 1929.

The influence of renal insufficiency on blood amylase deserves special mention. Some observers have claimed that amylase is retained, along with other substances, in cases of nitrogen retention (Stafford and Addis,[25] Meyer and Killian,[29] and Lawis and Mason).[30] Some experimental evidence indicates, on the contrary, that renal activity does not influence blood amylase. Thus van de Erve[37] found no change in the concentration of blood amylase following (*a*) ligation of the renal arteries, (*b*) induced polyuria and (*c*) anuria. In only one of our cases (no. 10) did we have an opportunity of making any observations on this problem. The high blood amylase (21 units) remained the same after a high nonprotein nitrogen content (120 mg. per hundred cubic centimeters) found in the blood on admission had been brought to normal limits by forced fluids. At operation a duodenal ulcer perforating into the pancreas was found.

SUMMARY

The concentration of amylase in adult human plasma was determined in sixty patients by means of a new method. Uniform values (from 4.3 to 6.8 units) were found in a series of twenty-five unselected cases in which there was no suspicion of disease of the acini of the pancreas. The same "normal" range of values was found in eleven additional cases in which the pancreas was actually examined and found to be normal, seven of these by palpation at operation and four by microscopic section after autopsy.

Definite deviations from this "normal" range were found in twenty-one of twenty-three cases in which disease of the pancreas was found either at operation or at autopsy. In most instances a moderate or marked increase in the blood amylase was found (from 7.8 to 150 units); in some a definite decrease occurred (from 0.5 to 3.1 units). The significance of these observations has been pointed out.

The determination of blood amylase has been of undoubted clinical value in a number of cases both in excluding suspected disease of the pancreas and in adding conclusive confirmatory evidence when the clinical picture was indefinite or vague. Jaundice, per se, has no influence on the amylolytic power of human blood unless disease of the pancreas is also present.

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37. Van de Erve, J.: Am. J. Physiol. **29**:182, 1911.

FRACTURES OF THE TRANSVERSE PROCESSES OF THE LUMBAR VERTEBRAE

A REPORT OF THIRTY-THREE CASES *

PAUL A. QUAINTANCE, M.D.

LOS ANGELES

My purpose in this paper is to reemphasize certain points in the mechanism, etiology, symptoms and diagnosis of fractures of the transverse processes of the lumbar vertebrae, and to report observations, especially with reference to union and the duration of disability, on a series of thirty-three cases seen in industrial practice over a period of two years.

Little or no mention was made of these fractures in textbooks on orthopedics and fractures by Taylor,[1] Albee,[2] Scudder,[3] Roberts and Kelly,[4] Preston,[5] Stimson,[6] Jones and Lovett,[7] Cotton [8] and Whitman.[9] Speed [10] and Hoffman [11] reported cases that were due to muscular action. Rhys,[12] Hartwell,[13] Davis [14] and Bierman [15] have written on the diag-

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* From the Golden State Hospital.

1. Taylor, H. L.: Orthopedic Surgery, New York, D. Appleton & Company, 1909.

2. Albee, F. H.: Orthopedics and Reconstruction Surgery, Philadelphia, W. B. Saunders Company, 1919.

3. Scudder, C. L.: The Treatment of Fractures, Philadelphia, W. B. Saunders Company, 1923 and 1926.

4. Roberts and Kelly: Fractures, Philadelphia, J. B. Lippincott Company, 1916.

5. Preston, Miller: Fractures and Dislocations, St. Louis, C. V. Mosby Company, 1915.

6. Stimson, Louis: On Fractures and Dislocations, Philadelphia, Lea & Febiger, 1910, p. 150.

7. Jones, Sir Robert; and Lovett, R. W.: Orthopedic Surgery, New York, William Wood & Company, 1923, p. 316.

8. Cotton, F. J.: Dislocations and Joint Fractures, Philadelphia, W. B. Saunders & Company, 1924, p. 142.

9. Whitman, Royal: Treatise on Orthopedic Surgery, Philadelphia, Lea & Febiger, 1927, p. 118.

10. Speed, Kellogg: Fractures and Dislocations, Philadelphia, Lea & Febiger, 1916, p. 251.

11. Hoffman: Med. Klin., 1914, vol. 10, quoted by Speed (footnote 10).

12. Rhys, O. L.: Pseudofracture of Transverse Processes of Lumbar Vertebrae, Brit. M. J., May 24, 1913; Healed Fractures of Transverse Processes of Vertebra, Ibid. **1**:873 (May 14) 1927.

nosis and etiology of these fractures, considering both direct trauma and indirect muscular action and also the simulation of fracture by accessory lumbar ribs. Kennedy [16] reported ten cases and reviewed the reported cases from the earliest (that of Ehrlich) in 1908 up to 1927.

ETIOLOGY

Knowledge of the embryology, anatomy and physiology of the structures of the back aids in determining the mechanism in fracture of the transverse processes of the lumbar vertebrae. The transverse and articular processes arise from the neural processes immediately behind the costal processes. In the lumbar region the latter become parts of the vertebrae. One center of ossification for each vertebral arch appears about the seventh week (Cunningham [17]). Of the secondary epiphyseal centers which appear at puberty there is one at the lateral extremity of each transverse process. Fusion of these with the shaft of the bone does not occur until the twenty-fifth year.

Anatomically, the transverse processes are slender, and quite thin vertically, and point horizontally and slightly backward and upward. The cancellous bone of their broad bases withstands greater stress than the more compact shafts; hence most fractures occur through the latter. The fifth and first processes are less frequently injured because of their protected positions. The quadratus lumborum muscles, arising from the fixed iliac crest and inserted into the tips of the transverse processes and the medial half of the twelfth rib, flex the lumbar spinal column laterally and draw the twelfth ribs downward. The longissimus dorsi, multifidi, intertransversarii and psoas majori act principally on the pedicles, mammillary processes and bodies of the vertebrae.

How are fractures of the transverse processes produced? That they result from direct violence or blows directly over the processes is self-evident. Upward dislocation of the ilium may fracture the fifth process; one case of this kind is reported in this series. That indirect violence from muscular action may fracture these processes was not recognized by Stimson [6] and was questioned by Rhys,[12] who regarded these separated transverse processes as developmental anomalies. Though he reported many cases with fractures unilaterally and bilaterally, he did not think that "strain distinct from direct violence can fracture these

13. Hartwell, J. B.: Colorado Med. **16**:78 (April) 1919.

14. Davis, G. G.: Fractures of Transverse Processes of Lumbar Spine, Surg. Gynec. Obst. **33**:272 (Sept.) 1921.

15. Bierman, N. J.: Am. J. Roentgenol. **10**:456 (June) 1923.

16. Kennedy, R. H.: Fracture of Transverse Processes of Lumbar Vertebrae, Ann. Surg. **85**:519 (April) 1927.

17. Cunningham: Text Book of Anatomy, New York, William Wood & Company, 1919, p. 104.

processes" and yet he did not see how (nor do I) "an injury (a force applied directly) could fracture transverse processes on both sides without also fracturing the spinous processes." He believed that considerable direct force was necessary to break a bone protected as these processes are and doubted fracture if there were no local external signs of injury.

Speed,[10] on the other hand, regarded many of these fractures as "caused by forcible contraction of the psoas and quadratus lumborum and longissimus dorsi muscles." He pointed out that fractures occur bilaterally and when the person is lifting heavy weights or is subjected to sudden strain in the forward flexed position. Nineteen cases due to muscular action were cited by him (Lange, Ehrlich, Hoglund, Hoffman[11]). Jones and Lovett[7] and Cotton[8] recognized both direct violence and indirect muscle strain as causes. Davis[14] believed that in practically all of these fractures the mechanism is one of indirect violence by muscular action. One of Davis' cases resulted from buckling or jack-knifing in a coal slide; there was a downward dislocation of the twelfth rib on the side of the fractures, again suggesting muscular action as the cause. In another case, fracture of three transverse processes followed an attempt to lift a loaded tram off a fellow workman. Kennedy[16] reported ten cases due to direct violence and cited Hoglund's three cases due to indirect muscular action. Two of the latter occurred while the patients were riding bicycles; the third while lifting a weight in a stooping attitude. In my opinion it must be recognized that violent contraction of the quadratus lumborum and other muscles of the back, with the thorax and pelvis both fixed, can and does result in fracture of one or more transverse processes. Separation of an ossific (epiphyseal) center, as suggested by Rhys, would not seem plausible after the twenty-fifth year of age.

In the thirty-three cases reported in this paper, direct external violence was responsible for the injury in eighteen instances, direct internal violence (ilium) in one and indirect muscular action in two. In two cases both direct and indirect violence were considered to have acted. In seven cases the mechanism could not be determined, as accurate histories of injury were not obtained. In two cases the diagnosis of fracture was questionable.

SYMPTOMS AND DIAGNOSIS

The most important diagnostic sign is tenderness localized immediately over the injured process. A history of direct trauma, ecchymosis and marked swelling are valuable when present, but often are absent. Backache, pain and stiffness in the back, weakness, muscle spasm and limitation in movements of the back usually are present in these fractures, but occur also in other injuries and diseases of the back, and

hence are of little value in differential diagnosis. Speed [10] mentioned abdominal pain and rigidity and also localized pain on voluntarily raising the lower extremity while in a supine attitude. The latter test is positive also in diseases of the vertebral bodies and intervertebral joints and disks, and hence is of little differentiating value.

Before the use of roentgenograms, fractures of the transverse processes never were diagnosed clinically. Now they are not uncommon. Anteroposterior (preferably stereoscopic) and lateral roentgenograms should be taken in practically every case of alleged injury to the back. They determine definitely recent or old injury to the bone, disease of the bones or joints and congenital anomalies, and help to eliminate from consideration certain widely advertised "pinched nerves" and "vertebrae out of place" (a phantom of the laity which is assuming serious importance in some states in the management of conditions of the back). Recent fractures present sharply-defined, ragged, irregular surfaces in contradistinction to the smooth, curved surfaces with interposed joint space seen in accessory rudimentary ribs. Healing fractures show callus as early as the third week. Ununited fractures usually are recognized by the displacement or attitude and position of the fragments, and may resemble lumbar ribs. Roentgenograms taken at intervals often will clear up the diagnosis in questionable cases. Old healed fractures often are difficult to recognize.

PROGNOSIS

Uncomplicated by other bony injury, fractures of the transverse processes usually heal completely with recovery of normal function of the back. Bony union usually takes place except where wide displacement of the fragments has occurred. Surgical removal of a fragment has not been found necessary in this series.

TREATMENT

Physiologic rest, the duration to depend on the severity of the injury, followed by early progressive active and passive motion are indicated. External heat in any form is comforting and probably favors the healing process. The value of diathermy and other electrical modalities is questionable, especially during the early stages of healing. The deep location of the transverse processes of the vertebrae and the rapidity with which diathermy diffuses through the tissues and circulating mediums (blood and lymph) leave a doubt in one's mind as to its value. Sedative diathermy, of course, is contraindicated. Absolute immobilization such as by plaster jacket or back braces, is believed to be unnecessary and inadvisable. Partial immobilization such as by rest in bed, simple strapping with adhesive plaster or a properly fitted corset-belt, with the back in the normal erect attitude should be maintained until

few were without symptoms in the back when first seen. Several had been given the diagnosis of "back strain" and came under my observation because satisfactory progress had not been made.

The accidents responsible for the fractures were blows or crushing injuries in seventeen, or slightly more than half of the cases, while in fifteen cases the patients fell from heights of from 2 to 30 feet (61 to 914 cm.). In one case the history of the accident causing the injury to the back was overlooked by the examiner, who confined his examination solely to an injured lower extremity.

The attitude of the patient's body at the time that the injury was sustained could not be determined in ten cases. It was found to be one of flexion in seventeen, or in over half of the series, and of extension (erect posture) in only six cases. This is of interest when one con-

TABLE 2.—*Relation of External Injury to the Mechanism of Fracture*

Classification	Mechanism	No. Cases	Per Cent
Local contusion, abrasion, swelling, ecchymosis or scarring	Direct	7	21.21
History, but no physical signs of trauma to the lumbar region	Probably direct	14	42.42
Trauma absent locally but present elsewhere (buttocks)	Indirect	2	6.06
History or physical signs of external trauma not recorded	Indeterminable	10	30.30
	Total	33	

siders the actual mechanism of the fractures, as illustrated in table 2. Attention is called to the fact that in only one third of the twenty-one cases of fracture resulting clearly from direct violence was there visible or palpable evidence, except for local tenderness, of injury to the soft tissues overlying the fractures. The absence of these signs is apt to lead the careless observer astray in his diagnosis. Only two of the thirty-three injuries were clearly the result of indirect muscular action. The regrettably high percentage of cases of indeterminable mechanism is due to inadequate histories and observations on the part of the examiners who first saw the patients.

Table 3 shows that the transverse processes of the first and fifth lumbar vertebrae, due to their protected positions, are least liable to injury. Those of the third vertebra were more frequently injured in the series studied. The right side showed a slight preponderance over the left in the actual number of processes fractured. That processes on both sides were fractured simultaneously in four cases suggests the mechanism of indirect muscular action in a higher percentage of cases than is evident from the figures in table 2. In one of these cases, how-

resorption of exudates has occurred and callous formation has begun. Passive and active motion should then be instituted and persisted in until a maximum return of function has been obtained. Light massage surrounding but not over the injured transverse processes aids both in resorption of hemorrhage and in healing. The therapeutic lamp is comforting to the patient and exerts a certain psychic effect.

OBSERVATIONS ON CASES

The present series consists of thirty-three cases of fracture of the transverse processes of the lumbar vertebrae occurring in a total of 42,634 hospital patients and outpatients, almost without exception industrially injured and sick. This is an incidence of one in every 1,430 patients. The ages of the patients studied varied between 18 and 64 years, the average being 37 years.

TABLE 1.—*Occupational Incidence of Fracture of the Transverse Processes of the Lumbar Vertebrae*

Occupation	No. Cases	Per Cent
Laborers	7	21.21
Truck drivers	7	21.21
Oil-field workers	4	12.12
Carpenters	3	9.09
Ditch diggers	2	6.06
Plumbers	2	6.06
Miscellaneous *	8	24.24
Total	33	100.00

* Including one each of the following occupations: teamster, painter, dairymilker, vulcanizer, electrician, shipping clerk, office manager and football player.

The occupational incidence is shown in table 1. That unskilled laborers head the list indicates merely that the same factors which make unskilled laborers of men also make them the most careless workmen and hence those most liable to injury. The equally high incidence in truck drivers emphasizes the increasing importance of automotive vehicles in industrial activities. Oil-derrick workers, carpenters and ditch diggers are unduly exposed to injury from falling objects or from falls.

The interval elapsing between the time of injury and the first observation of the patient varied from a few minutes to seventeen years. Ten patients were seen within twenty-four hours, nine within four weeks, eight within six months and six at various times in excess of six months after the original injury. In the cases in which the fractures were of long standing they were discovered during routine examinations for various related and unrelated complaints, a fact which emphasizes the importance of careful and complete examination of every patient. A

ever, a severe crushing blow fractured spinous and transverse processes of both sides and bodies of the vertebrae as well.

In the thirty-three cases studied there were twenty-two instances of associated injury to the bone. These included five fractured ribs, usually the twelfth, eight chip or compression fractures of the bodies of the lumbar vertebrae, two fractures of spinous processes and seven fractures of the pelvic bones, usually the ilium inclusive of one fracture of the coccyx. One case was complicated by traumatic spondylolisthesis. In thirteen cases, over one third of the total number, there were from slight to advanced hypertrophic changes on the bodies of the vertebrae.

TABLE 3.—*Relative Incidence of the Processes Fractured* *

Vertebrae Involved	Total	Right	Left	Per Cent	
				Right	Left
I	2	2	0	2.66	.....
II	17	9	8	12.00	10.66
III	27	15	12	20.00	16.00
IV	31	13	8	17.33	10.66
V	8	4	4	5.33	5.33
Total	75	43	32	57.33	42.66

* Both sides were involved in four cases.

TABLE 4.—*The Relation of Displacement to Healing* *

Status	Fractures	Per Cent	Displacement	Per Cent	No Displacement	Per Cent
Union	38	50.66	13	17.33	25	33.33
Nonunion	14	18.67	14	18.67	..	.....
Fracture too recent for healing	23	30.67	9	12.00	14	18.67
Total	75	100.00	36	48.00	39	52.00

* Gross malalignment was observed in two instances of healing.

The aforementioned evidences of associated injury and disease are of interest only so far as they affected the period and extent of disability.

Study of the roentgenograms disclosed interesting facts relative to the healing of these fractures as shown in table 4. In every one of the fourteen instances of nonunion, wide displacement of the separated fragment had occurred. Union had taken place, however, in 50 per cent of the fractured processes, even though displacement had occurred in approximately one third of these. In 30 per cent of the fractures, insufficient time had elapsed for healing to occur. The presence of bony union and nonunion in the same patient was observed repeatedly, ruling out constitutional deterrents to healing. In two instances healing occurred, although there was gross angulation of the separated processes.

DISABILITY

The disability is the primary consideration of the patient and, in these days of medical and surgical compensation of the employer and the insurance carrier as well. It is also the major interest of the physician, since it is the most accurate measure of functional recovery of the injured parts. Thomas,[18] in seventeen uncomplicated cases of fractured transverse processes, reported a permanent disability of from 30 to 40 per cent, which seems high. Skillern [19] found ablation of a fractured process and massive callus necessary for relief from pain after five months of disability, and noted immediate relief with return to work after two months.

In the present series of thirty-three cases the period of disability was greatly prolonged in nine patients who sustained associated fractures of bodies of the vertebrae, pelvic bones or bones of the extremities.

TABLE 5.—*The Average Number of Processes Fractured and the Period of Disability in Twenty-four Cases Without Other Injury to the Bone*

Period of Disability *	Age, Years	No. of Cases	Average Number of Processes
0-1 month	18-60	5	1.8
1-2 months	20-55	5	2.0
2-3 months	22-64	6	2.3
4-6 months	31-44	4	2.5
6 months and over	30-39	4	2.25 †

* The minimum disability was 0 (3 cases) and the maximum disability 7 months (3 cases).

† Separation of the lumbar rib in one case.

The few instances of permanent disability occurred in this group. In the remaining twenty-four cases of uncomplicated fracture of the transverse processes the temporary disability ranged from zero in three cases to slightly more than seven months in three other cases. The relation of age and the number of processes fractured to the period of disability is shown in table 5. In the patients with actual disability for less than one month the ages ran from 18 to 60 years, whereas in those disabled from six to seven and one-half months, the ages varied between 30 and 39 years. This indicates that age is a negligible factor in disability, at least in this series. The average age of the patients was 37 years. Two thirds of the patients are seen to have had a disability of less than three months, with the period from two to three months claiming slightly the larger number. It should be stated that the period of disability in every

18. Thomas, A.: Spinal Fractures, Colorado Med. **25**:19 (Jan.) 1928.

19. Skillern, P. G., Jr.: Ununited Fracture of Transverse Process of Fifth Lumbar Vertebra, with Massive Callus, S. Clin. North America **2**:283 (Feb.) 1922.

case has been reckoned from the date of injury to the time when the patient actually returned to and was able to continue his regular work. In seven instances the patients were doing light forms of work for periods ranging from three weeks to five months prior to the actual discontinuation of temporary disability. In other words they had a partial disability, with compensation adjusted accordingly, until they were able to resume their regular work. The period of disability is seen to increase in approximately the same ratio as the number of processes fractured.

The effect on the period of temporary disability of factors other than the extent of the injuries is of both academic and practical interest. For example, one patient continued with his work for four weeks after his injury; then, on learning that he had sustained a fracture, he was disabled for the same type of work for a further period of four weeks.

TABLE 6.—*Disabilities in Twenty-four Patients with no Other Injury, Who Received Ambulatory Treatment and Were Allowed to Rest in Bed*

Type of Treatment	Duration of Treatment, Weeks	No. of Cases	Average No. of Processes Fractured	Average Disability, Weeks
Ambulatory	.....	9	2.00	4.5
Rest in bed	Under 1	3	2.00	10.0
	1 to 2	3	1.33	17.0
	2 to 3	4	2.50	12.5
	3 to 4	3	2.66	25.0
	4 to 5	1	3.00	18.0
Undetermined	.....	1*	....	....

* No data in history.

Another patient alleged persisting disability in the absence of physical signs; at the end of four months he confided in the examiner to the extent of offering $50 for a surgeon's report so executed as to secure a permanent indemnity for disability through a personal accident policy that he had carried for several years. When at attempt was made by the examiner to have this patient sign an agreement to that effect, his alleged disability immediately ceased and he has not been heard from since. Still another patient, who sustained his injury during a football game, finished the game and resumed his usual work the following day complaining only of a "sore back" for a few days. His fracture was discovered by the examiner several months later during an examination for a subsequent injury. Complicating osteo-arthritis was felt to have prolonged somewhat the period of temporary disability in a few cases.

In table 6 is given a comparison of the periods of disability in patients who had ambulatory treatment only and in those who had rest in bed for various periods preceding the ambulatory treatment. In the twenty-four uncomplicated cases of fracture of the transverse proc-

esses, nine, or slightly more than one third of the patients, were treated by the ambulatory method alone, that is, by partial immobilization, physiotherapy and relative rest of the muscles of the back. Their average temporary disability was four and one-half weeks, and the average number of processes fractured was two. Though not indicated in the table these fractures presented little or no displacement of fragments, a factor that I believe has a direct bearing on the rapidity of healing and, hence, on the duration of temporary disability. The patients requiring increasing periods of rest in bed show a relatively larger number of transverse processes fractured and a corresponding increase in the duration of temporary disability. In Kennedy's [16] series of ten cases the period of hospitalization ranged from two to thirty-two days. In my fifteen patients with uncomplicated fractures who required hospitalization, the actual stay in the hospital varied from three to thirty-five days, the average period being seventeen days.

REPORTS OF CASES

CASE 1.—C. E. M., a pipe fitter, aged 50, sustained a crushing injury in the lumbosacral region in January, 1911. While he was on his hands and knees the corner of a two-story bunkhouse fell on him. He was immediately disabled, walked with crutches for five years and did no work for ten years. During the last six years he has worked steadily as a fitter Roentgenograms (fig. 1) sixteen years later showed a fracture of all the transverse processes on the right side and of three on the left, fracture of the twelfth rib on the right and compression fracture of the body of the fifth lumbar vertebra. The fractured fragments were widely displaced (a maximum distance of 5 cm.) from the parent bones, except for those of the fourth and fifth transverse processes which had united. The distal end of the fractured twelfth rib lay in an inverted position in the soft tissues, 4 cm. below its parent bone. The prolonged disability in this case was due chiefly to the compression fracture of the body of the fifth lumbar vertebra. The case illustrates the point that surgical removal of ununited displaced fragments is not indicated unless they are causing symptoms of pressure.

CASE 2.—A. E. M., a carpenter, aged 38, on May 11, 1927, while stooping over, was struck in the left lumbar region by two falling scantlings. There was an abrasion contusion and exquisite tenderness over the left upper lumbar regions. Roentgenograms (fig. 2A) showed fracture of the left transverse processes of the second and third lumbar vertebrae with slight lateral displacement of the third. This patient still complained of aching pain in and stiffness of his back seven months after the injury, although x-ray pictures at four and a half months (fig. 2B) showed healing in good position.

CASE 3.—L. I. McG., an oil driller, aged 44, on Aug. 16, 1927, was struck in the left lumbar region by a timber, 2 inches by 8 inches by 12 feet (5 by 20 by 365 cm.), which toppled over from a vertical position. He was faint and felt immediate pain. He remained in bed at home for one week, and then consulted a physician who, after what must have been a very superficial examination, diagnosed the condition an "injury to the back" and prescribed physiotherapy. Massage

continued to be so painful after four weeks that x-ray pictures were taken (fig. 3A). They showed fracture of the left transverse processes of the third and fourth lumbar vertebrae with good callus and good position. At three months (fig. 3B) union was complete. The patient continued to complain of pain in the back and disability in the absence of substantiating physical signs. It developed that he was maliciously alleging disability in the hope that he might secure indemnity from a personal accident policy. Exposure of his attempt to bribe the

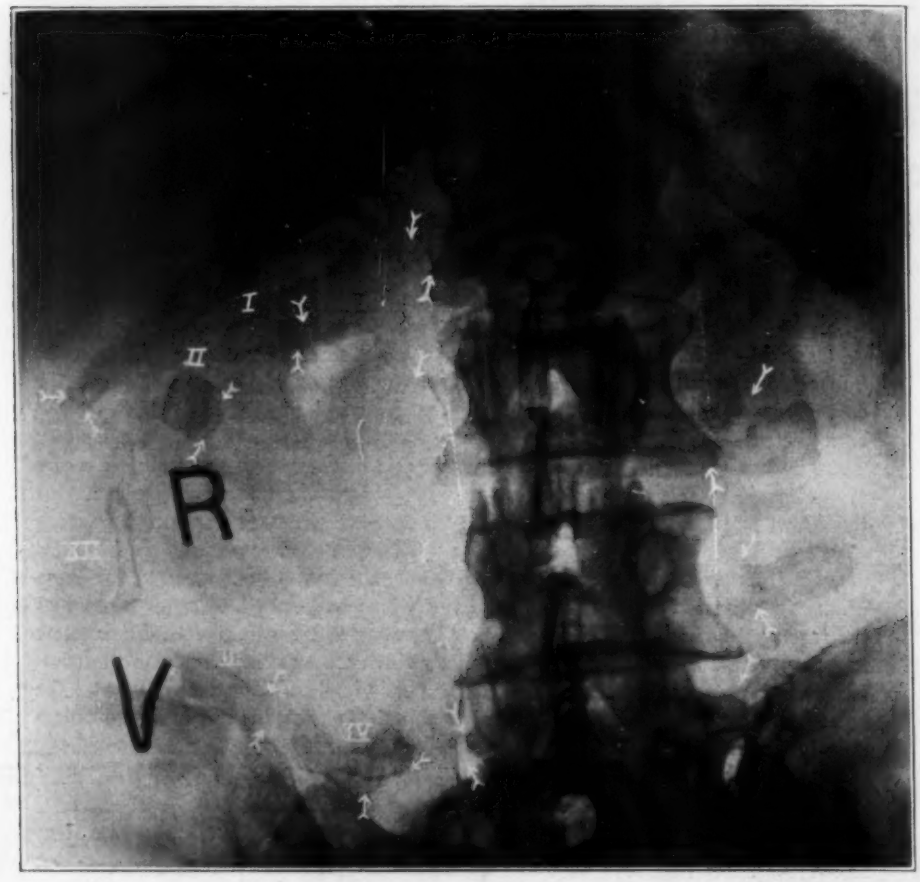

Fig. 1 (case 1).—Fracture of all transverse processes on the right, and of three on the left; fracture of the right twelfth rib and compression fracture of the body of the fifth lumbar vertebra.

physician resulted in a sudden termination of his disability four months after the injury.

CASE 4.—This case illustrates an unquestionable instance of fracture by indirect violence (muscular action). H. M., a truck driver, aged 28, on March 10, 1928, was climbing into the back end of his truck when his foot slipped off the angle plate and he fell backward to the ground, alighting in a sitting posture on his right

Fig. 2 (case 2).—*A*, fracture of the left transverse processes of the second and third lumbar vertebrae, with slight lateral displacement of the third; *B*, appearance of fractures four and a half months later, showing healing in good position.

Fig. 3 (case 3).—*A*, fracture of the left transverse processes of the third and fourth lumbar vertebrae, with good callus and good position, four weeks after injury occurred; *B*, complete union after three months.

buttock. He stated definitely that he did not strike his back on anything. On regaining his feet and straightening up, he had pain in the lumbar region and in the right hip. He continued his deliveries, but with every second step experienced "sharp catch-like pains" in the right lumbar region; these became so severe after an hour or two that he could scarcely walk. His physician diagnosed the condition as "a spained back" and applied adhesive strapping. The patient remained in bed for four days. When examined on the sixth day there was marked tenderness over the right midlumbar region, with moderate spasm of the right sacrospinalis muscles. Left lateral bending, torsion and forward bending were painful and restricted. There was no external sign of injury on the skin of the lumbar region,

Fig. 4 (case 4).—Fracture of the right transverse process of the third lumbar vertebra due to muscular action.

but an area of tender cutaneous ecchymosis was found in the right gluteal fold. Roentgenograms (fig. 4) revealed a fracture of the right transverse process of the third lumbar vertebra. Temporary disability lasted for four weeks.

CASE 5.—A. L. G., a truck driver, aged 31, on March 12, 1928, while stooping, was struck in the right lumbar region by a 25 pound (11.3 Kg.) cast iron hoist weight. Pain and disability were noted immediately. For one day there were stinging shooting pains down the right thigh and leg, associated with numbness. Examination revealed an abrasion contusion in the right midlumbar region with tenderness in the lower lumbar region and spasm of the right sacropinalis muscles. Bending of the back was restricted and painful. Roentgenograms on the day of injury (fig. 5A) revealed fracture of the right transverse processes of the third, fourth and fifth lumbar vertebrae with a maximum lateral displacement of 1.5 cm.

Fig. 5 (case 5).—*A*, fracture of the right transverse processes of the third, fourth and fifth lumbar vertebrae; *B*, appearance of the fractures at two months, showing union of the fifth process, good callus on the third, and nonunion of the fourth process with slight callus and displacement.

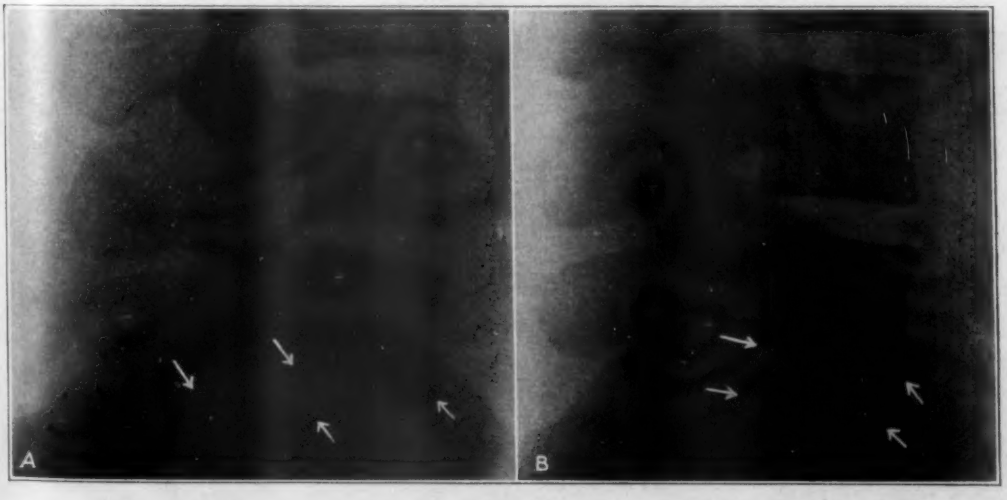

Fig. 6 (case 6).—*A*, fracture of the articular processes of the fourth and fifth, with anterior displacement of the fourth lumbar vertebrae; *B*, complete reduction of the anterior dislocation.

of that of the fourth lumbar and a minimum displacement of 0.5 cm. of that of the fifth. Roentgenograms taken after two months (fig. 5B) showed union of the fifth process, good callus on the third and nonunion of the fourth process, with slight callus and displacement. This case illustrates the influence of displacement of the fractured fragment on the rapidity of the healing process.

CASE 6.—H. G., a Mexican laborer, aged 29, on Jan. 10, 1929, was struck on the right side and hip by a falling skip, causing him to fall across a ledge measuring 2 by 6 inches (5.1 by 15.2 cm.), where he was pinioned. Pain in the lower lumbar and right pelvic regions and loss of sensation and motor power in both

Fig. 7 (case 6).—Anteroposterior view, at the eighth week, showing little improvement in the lateral displacement.

lower extremities were immediate. Examination revealed severe contusion ecchymoses over the right hip, flank and lumbar regions with group paralyses and anesthesiae involving both lower extremities, especially the right. Voluntary control of both feet was lacking. Lateral roentgenograms (fig. 6A) taken on the day of the injury, showed fracture of the articular processes of the fourth and fifth with anterior displacement of the fourth lumbar vertebra equal to almost the diameter of its body. Under ether anesthesia, Dr. Herzikoff, who has permitted report of this case, was able to reduce the anterior dislocation completely (fig. 6B).

although the lateral displacement was not materially improved, as is seen in the anteroposterior x-ray picture taken at the eighth week (fig. 7). This roentgenogram shows well the fractures of the right first, second, third and fourth and left third, fourth and fifth transverse processes, as well as the fractured articular processes. At the eleventh week the patient had regained almost normal sensation and moderate motor power in all muscles except those controlling the right foot.

The following case illustrates fracture of the transverse processes by muscular action.

Fig. 8.—Anteroposterior view of oblique fractures of the right, second, third and fourth transverse processes and fracture of the right eleventh rib, at its angle

CASE 7.—G. B. Q., white, an electrician, aged 34, on April 8, 1929, fell backward eight feet (243 cm.), alighting on the right hip, scapular regions and head on a smooth concrete floor. He definitely stated that there were no projections or loose objects on the floor. He had immediate and persistent pain throughout the right lumbar and lower dorsal regions but no ecchymosis or other external signs of injury either then or during the ensuing days. An anteroposterior roentgenogram (fig. 8), taken three weeks after the accident, revealed oblique fractures of the right second, third and fourth transverse processes and fracture

of the right eleventh rib at its angle, with no definite evidence of callus. He was still in bed three weeks after the injury occurred and the area over the fractured bones was tender.

SUMMARY

1. The literature for the last fifteen years on fracture of the transverse processes of the lumbar vertebrae has been reviewed.

2. Most writers recognize that these fractures result from both direct external violence and indirect internal violence (muscular action); a few deny that these fractures can result from indirect violence.

3. Thirty-three cases are reported, in two of which fracture undoubtedly resulted from indirect muscular action. In 42 per cent of the cases of this series, fracture unquestionably was due to direct external violence.

4. The transverse processes of the second, third and fourth lumbar vertebrae constituted 85 per cent of the total number of fractures in this series. Fracture occurred bilaterally in the same patient in four instances.

5. The patient's body was in an attitude of acute flexion in slightly more than 50 per cent of the cases at the time that the fractures were sustained.

6. In nine (27 per cent) of the thirty-three cases, associated fractures of the pelvic bones, the bodies of the lumbar vertebrae or the ribs occurred. Hypertrophic arthritis was present in thirteen (39 per cent) of the patients.

7. Of the seventy-five instances of fracture of the transverse processes, nonunion resulted in fourteen (or 18 per cent). In every instance of nonunion, the fragments were widely displaced.

8. Temporary disability in the twenty-five cases uncomplicated by other fractures lasted, on the average, slightly more than ten weeks. The minimum period of disability was zero, and the maximum slightly more than seven months. None of these patients was permanently disabled and in none was resection of the fractured processes found to be necessary.

CONCLUSIONS

1. Fractures of the transverse processes of the lumbar vertebrae result from both direct external violence and indirect internal violence (muscular action).

2. Failure to appreciate this fact, to examine patients carefully and to take roentgenograms results in frequent error in diagnosis.

3. Nonunion usually is the result of displacement of the fractured fragments.

4. The duration of disability often is influenced as much by psychic and personality factors and by the provisions of state compensation laws as by the severity of the injury itself, as indicated by physical examination and roentgen observations.

GROSS AND MICROSCOPIC STRUCTURE OF THE THYROID GLAND IN MAN*

WILLIAM FRANCIS RIENHOFF, JR., M.D.
BALTIMORE

Numerous investigations concerning the structure of the thyroid gland have been made in the past, but these, for the most part, have dealt with the morphology of the follicles, about which there still seems to be marked differences of opinion. It is my purpose in this report to present the results of a study of the normal human thyroid and also of the gland in cases of exophthalmic goiter from the standpoint not only of the individual follicles, but also of the structure of the gland as a whole and of the various subdivisions or units into which the thyroid is divided.

That the follicle of the thyroid represents the ultimate histologic unit of the gland is now conceded by all investigators, but in the intensity of the researches concerning the shape and size of these follicles and their discontinuity, its morphologic structure as a whole, and the manner in which this glandular mass is again subdivided into larger regions or areas composed of many follicles, has not been described. Heretofore, only very small areas of the gland have been studied by means of the wax plate reconstruction method, with the result that the morphology of only a few follicles has been determined. These investigations will be referred to later. In this study not only was the wax plate reconstruction used to investigate a larger area of thyroid tissue than had heretofore been reconstructed in wax, but the method of maceration and microdissection was also employed. By utilizing this larger area of the thyroid reconstructed by the wax plate method, I have been enabled to visualize the actual spatial relationship not only of the individual follicles, but also of the various regions, and to determine the presence or absence of a true lobulation of the gland. Reference was continually made to the stained sections during the process of transference to the wax plates of the tracings of the photographs made of them, in order that all epithelial elements would be included and the existence of interacinar cell rests, fetal or adult, might be determined. Serial sections of 10 and 20 microns, respectively, in thickness were studied for this purpose. No evidence of the presence of undifferentiated epithelium between the acini or

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* From the Carnegie Institute of Washington, Department of Embryology, and the Department of Surgery, Johns Hopkins University.

follicles could be discovered in any of the sections. No epithelium, except that which is completely differentiated, and also which presents the arrangement of the normal parenchyma of the thyroid, exists in the adult gland. There is a great variation in the size of the individual follicles, and although there are in the normal gland many small ones in which a lumen is scarcely visible, nevertheless, from the histologic point of view, these smaller follicles are just as much and just as important a portion of the parenchyma of the gland as the larger follicles. It was evident, after examining the stained serial sections in conjunction with constant reference to the wax model, that small clusters of epithelial cells not arranged in acinar formation which apparently lay between various follicles, the latter having been cut in that particular section through their maximum diameter, were merely the beginning of other follicles situated in the gland and also in the model at different levels. A tangential section through the dome of a spheroid-shaped follicle or the end of a tubule-shaped one, which does not expose the lumen of the follicle, gives the impression of a group of interacinar cells which have not assumed the form and arrangement of an adult follicle or the remainder of the parenchyma of the thyroid. This, however, is an illusion and no evidence of any interfollicular fetal cell rests or clusters of differentiated epithelium, which were not a portion of the parenchyma, was demonstrable. The presence of many small follicles interspersed throughout the gland between the larger ones was also of interest. From the small size of the lumen in these follicles it might be suggested that they were probably not functioning to so great an extent, if at all, as the larger ones, and that they formed as it were a sort of a reserve supply. (Dr. Bensley [1] suggested that no gland functions equally throughout its entirety when stimulated, so that one should not expect all the follicles to be of the same size or to contain the same amount of colloid.) The noticeable reduction in number of these smaller follicles in the pathologic thyroid associated with exophthalmic goiter was striking and would seem to suggest that these small follicles of thyroid epithelium are capable of enlarging when called into action. The wax model demonstrated the diversity in size and the variability in shape of the inner margin of the epithelial lining of the follicles, and therefore, the internal form, with their relative position, but the structure of the gland as a whole, the morphology of the regions into which the gland is divided and the true external form of the follicles could be determined only from the dissected specimens.

Although larger areas of the normal human thyroid and the thyroid in exophthalmic goiter were reconstructed in wax than ever before

1. Personal communication to the author.

described, still the small block of gland sectioned was inadequate to determine the morphology of the gland as a whole, the structure of the various subdivisions or units into which the thyroid is divided and the true external form of the follicles. The wax reconstruction of the thyroid in exophthalmic goiter, as already stated, showed an enormous increase in the size of the follicles, and indentations in the models of these follicles bore witness to the papillomatous infoldings of the epithelium. However, the small follicles which have been observed, in stained sections of the gland in exophthalmic goiter, to have been situated in a position peripheral to that of the larger follicles were shown both by the wax plate reconstruction and more strikingly by the maceration and microdissection to be entirely discontinuous from the larger follicles. The small ones were distinct individual follicles and not, as has been suggested, pseudopodial outpouchings of the epithelial wall of the large follicle. The follicles, both large and small, have a smooth external epithelial wall. The only papillomatous or pseudopodial irregularities are those observed inside into the lumen of the follicle. The true external form of the follicle was brought out by the maceration and dissection technic, whereas the internal shape or cast of the inside of the follicle was shown better by the wax models. By employing maceration and microdissection, it was possible to demonstrate that the main mass of thyroid gland is divided and subdivided into many connecting or annectent bars, bands and plates of parenchyma, which in turn are composed of individual, discrete and discontinuous follicles. There are no distinct and true lobules in the thyroid, and it is incorrect to speak of it as a lobulated gland. These plates, bands and bars of parenchyma are separated by clefts and spaces normally filled with tissue of mesenchymal origin, such as blood vessels, connective tissue, lymphatics and nerves. They vary markedly in shape and size, the gland being irregularly broken up by the clefts and open spaces which form by their connections a fenestrated labyrinth in the gland mass. These bars, bands and plates are always connected one with another, and no isolated regions of parenchyma completely surrounded by connective tissue were observed. The presence of an area of parenchyma in a stained serial section which seemed to be completely surrounded and isolated by connective tissue was proved to be an illusion. Such an area was reconstructed in the exophthalmic gland and will be described later in this paper. The parenchyma on the anterolateral surface was disposed in rather flat platelike regions with, of course, connecting bars and branches of tissue associating these areas with contiguous parenchymatous areas of the inner zones of the gland. In general, the surfaces of these plates were convex and parallel to the surface of the lobe. The surface

and long diameter of the plates, annectent bars and bands were usually parallel to the long axis of the body, and therefore, to the greater axis of the entire lobe. The anastomosing system of clefts and open spaces, which were previously filled with mesenchyme, were also roughly parallel to the long axis of the lateral lobe. The follicles were discontinuous and individual structures not connecting with each other. The shapes vary from a perfect sphere to a long narrow tube with almost all conceivable types of intervening shapes. Their size ranged from 0.02 to 0.897 mm.

MATERIALS AND METHODS

In this study of the morphology of the normal thyroid and the gland in exophthalmic goiter, two methods were employed: (1) the wax plate reconstruction and (2) maceration and microdissection.

The normal thyroid tissue used in this study was obtained from the pathologic laboratory of the Johns Hopkins Hospital. The tissue was carefully chosen from ten young adults who had succumbed to maladies which would not have affected the thyroid gland, or to postoperative deaths and accidents. The localities in which the subject was born, raised and was living were taken into consideration so as to eliminate the possibility of a patient having resided in a goitrous district. All of these patients were inhabitants of parts of the state of Maryland situated at or very near sea level.

The thyroid glands from eight patients with exophthalmic goiter were obtained from persons operated on by me, so that the clinical history, physical signs, preoperative treatment, operative observations and handling of the thyroid tissue after operation were known at first hand. Hence there remains no doubt that the patients from whom the glands were removed were suffering from typical and extreme cases of primary exophthalmic goiter. In the case from which the wax reconstruction was made, and from which part of the dissection is also shown, no iodine had been used as a preoperative measure, and so far as could be ascertained no iodine or goiter remedies in any form had ever been given to the patient. The case was a clinically typical one of exophthalmic goiter with a basal metabolism rate of plus 92. There were vascular thrills and bruits at the poles. A preliminary partial lobectomy was performed to secure thyroid tissue from a typical case of exophthalmic goiter which had been histologically unaffected with iodine. After the preliminary partial lobectomy had been done, the patient was treated with a compound solution of iodine in the usual manner and a later subtotal bilateral lobectomy was followed by complete recovery. The tissue removed at the preliminary partial lobectomy was used for both the wax plate reconstruction and the dissection described and shown in this report. A comparison between the two reconstructions before and after the administration of iodine will be made in a later paper. In the remaining seven cases of exophthalmic goiter, iodine was given to the patient for the first time and only used over a very short period. The dosage was 10 minims (0.6 cc.) three times a day for ten days. With the exception of this, these patients had received no iodine before admission to the hospital. The average basal metabolism rate was slightly above plus 60.

A block 4 mm. square was cut from a normal thyroid gland and also out of the tissue removed from the thyroid in the case of exophthalmic goiter already mentioned, following their fixation in a diluted solution of formaldehyde U. S. P. (1:10) for several months. Each of these blocks was then dehydrated in 50,

60, 70, 80 and 95 per cent solutions of alcohol for twenty-four hours. They were then placed in absolute alcohol for twenty-four hours, changes being made to a new solution twice during that time. Following this, they were subjected to a solution of absolute alcohol and ether for another twenty-four hours. The blocks were then placed in 2, 6, 8, 10, 12 and 14 per cent solutions of celloidin for twenty-four hours each. They were then embedded on separate blocks and hardened in chloroform, after which they were kept in equal parts of 85 per cent alcohol and glycerin. Sections were cut of both blocks serially at a thickness of 20 microns, after which they were stained with hematoxylin and eosin. Other blocks 4 mm. square were similarly treated and cut serially in sections of 10 microns in thickness. The series of sections 20 microns in thickness, however, were used for the wax plate reconstructions described in this report, not only for the normal gland but also for that of the gland from the case of exophthalmic goiter. The stained sections were mounted serially on slides in groups of thirty sections to each slide. Five slides were used, totalling 150 sections. These slides were then photographed on Eastman's bromide paper, 11 by 14 inches (27.9 by 35.5 cm.), being projected at a magnification of 75 times. Many exposures were made, and finally the exposure which brought out the finest detail was found to be that of six seconds. The bromide plates were at once developed, dried and compared with the stained sections for microscopic detail. This checking of each bromide plate was made to guard against the possibility of losing some detail due to either the necessity of changing the exposure because of heavier or deeper staining of any given section or, on the other hand, to the freshness or staleness of the developing solutions. Sometimes insufficient washing would brown the bromide paper to such an extent that another exposure would have to be made to avoid losing some of the microscopic detail. The thickness of the section being 20 microns, times the linear magnification of 75, results in 1,500 microns, or 1.5 mm., which equals the desired thickness of a wax plate required to give the proper depth at a magnification of 75 times. Wax plates of the thickness of 1.5 mm. were then molded and cut 19.6 cm. square. These plates were cut accurately at right angles so that when piled one on the other they formed a perfect cube. As shown in figure 1, another geometrically accurate right angle was formed by strips of pasteboard held in place by thumb-tacks on a drawing board covered with smooth paper. The edge of the bromide plate, as shown, was set inside the pasteboard right angle and the edge of the section which corresponded to the exposed portion of the plate was made equidistant on two sides by means of a 1 cm. isinglass ruler. This eliminated the error of slight distortion due to the section being exposed somewhat unevenly as regards the edge of the bromide plate. The plate was then fastened down on the top of a piece of tracing paper which in turn lay on a 1.5 mm. wax plate. By the use of a right angle shown in figure 2, two straight lines were drawn across the board, later across the bromide plate, and were then traced on the wax beneath. These lines cut each other at right angles near the center of the plate and formed lines of orientation for the later stacking of the wax plates. Two small nails or pins were driven into the drawing board on these lines at the extremities of the orientation lines so that the right angle ruler could be replaced each time with accuracy. Each bromide plate and its underlying wax plate were so marked through the entire series of both the normal and the pathologic thyroid sections. After the lines of orientation on the bromide paper and the underlying wax plate had been marked, the inner margin of the epithelial lining of each follicle was traced with the utmost care and thus transferred by means of the carbon paper to the wax plate beneath.

All epithelial cells in groups or clusters were traced in a similar manner regardless of whether or not a lumen was present. If only a few cells were evident, merely a solid mark, proportionate in size, was made. In the tracings, the outlines of the larger bands of connective tissue were also made in order to bring out in the model the ramifying tendency of these bands. The figures shown are actual photographs of the method reduced 5.75 times, and it is evident that the definition of the follicles in an unreduced 11 by 14 film would be much greater. The tracing was done with a steel stilet ground to a very smooth and pointed tip, so that greater detail could be obtained. Constant reference to the original stained section was made in order to be certain of the presence of all epithelial structures. Owing to these precautions, no groups of epithelial cells were omitted because not only was the bromide paper film checked with the stained section under the microscope, but the tracing on the wax plate was also corrected by comparing it

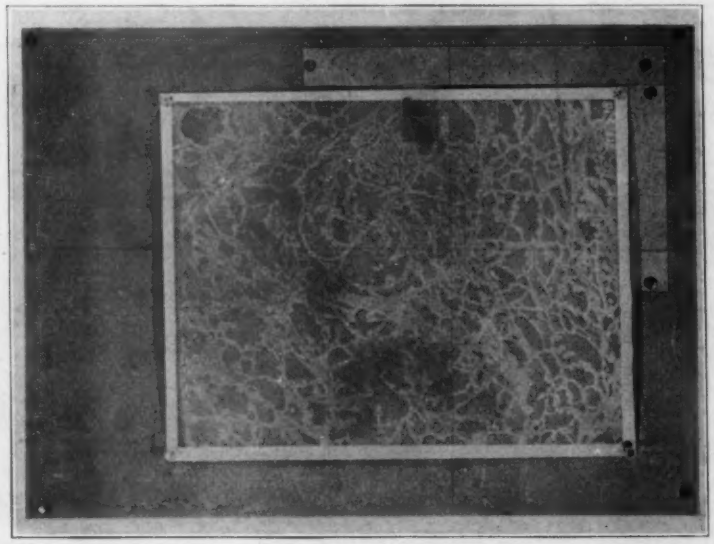

Fig. 1.—Photograph on bromide plate of a microscopic section from exophthalmic goiter. The wax plate is covered by carbon tracing paper placed beneath the bromide film. The drawing board with right angle pasteboard slips and orientation lines with guiding nails at their extremities is shown. An isinglass centimeter rule is placed between the exposed edge of the plate and the right angle pasteboard strips. Reduced to × 14 from × 75.

with the microscopic section, and in addition with the bromide film. The number of the slide, the row of the section and the number of the section in the row were photographed on the bromide paper at the time of exposure, by merely writing on the bromide plate with a pencil and then completing the exposure. The number was then traced on the wax plate. The entire microscopic detail of the bromide film was thus transferred to the wax plate. With a small knife the outline of the epithelial lining of the follicle was cut as shown in figure 3 for the normal and figures 4 and 5 for the exophthalmic gland. This was done by placing the wax plate on a square piece of plate glass. The knife would slide over the glass surface without engaging it. A burr, however, was formed on the upper surface

of the wax plate where the knife would split the traced line denoting the epithelial lining. A perpendicular cut was always attempted, to avoid the distortion of the positive model that would result from a slanting cut. The burr formation caused the wax to protrude slightly above the surface of the plate in general. The wax plate was then turned face down on the plate glass and a roller run over it, which exerted a certain amount of pressure on the entire plate, but more on the burrs which coincided with the carbon lines of the traced epithelial lining and the cut out portions. The glass plate having been carefully cleansed, it was immediately marked with the carbon lines outlining the follicles, and due to the wax burrs the cut out pieces became fastened to the glass so that the wax plate itself could be lifted away leaving the cut out portions adherent to the plate and in their correct position relative to one another. To meet these requirements the glass plate must be absolutely dry and cold. It will invariably happen that some

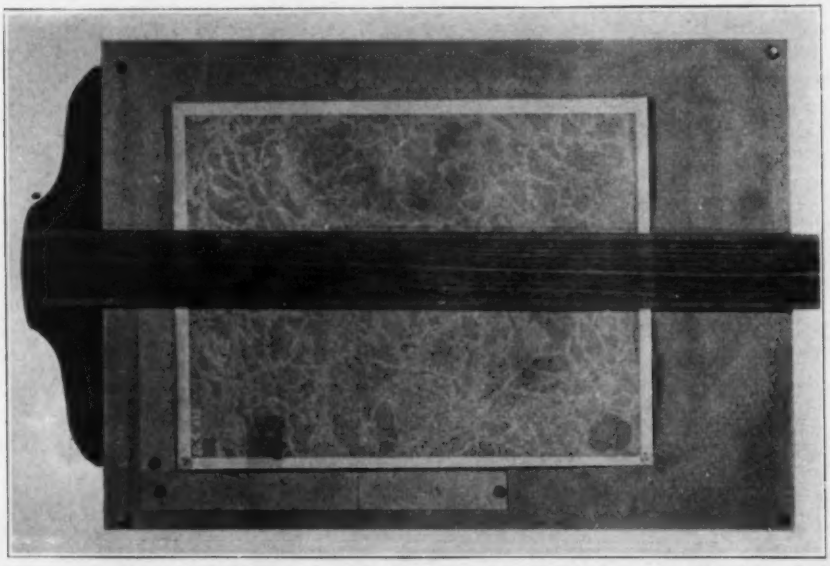

Fig. 2.—Right angle rule for drawing lines of orientation on a bromide film which also marks the wax plate beneath. The ruler is held in place not only by its right angle but as shown in the photograph by the nails at the extremities of the lines of orientation. Reduced to × 14 from × 75.

small pinpoint pieces of cut out wax, representing a few epithelial cells, will be moved out of place, but the mark on the glass where it originally impinged is usually sufficiently evident to replace the small piece accurately. In order that all cut out portions shall be absolutely true in their original position and especially with the relation to one another, the wax plate from which the pieces were removed is placed underneath the thin glass plate on which the cut out portions have become fastened, and these excised pieces are readjusted exactly over the area from which they have been cut out. They are firmly pressed down on the glass and then wired together by dropping a short piece of heated copper wire (no. 2) over each piece (fig. 6). If any pieces have been lost, displaced or remain undislodged in the plate, they can be detected readily and can be replaced by retracing one

follicle on a separate piece of wax. The network of disconnected pieces of wax wired together is then removed from the glass without distortion by passing a warmed spatula between the pieces and the glass. Again a comparison between the positive and the negative wax follicles can be made. The positive is then placed on marked cardboard squares to preserve its identity and prevent it from warping because of its weight. Each section was thus magnified 75 times and transferred to a positive wax plate formed by wiring the individual pieces together, and to a negative wax plate formed by cutting out the pieces representing the lumen of the follicle. These plates were then piled on one another by their orientation lines serving as a guide so that no axial distortion of the model might occur, and the exact spatial relation of the follicles was maintained. The size and shape of the inside of the follicles were shown. The course of the fibrous septums was also brought out. After the piling of the plates was finished, as many as possible

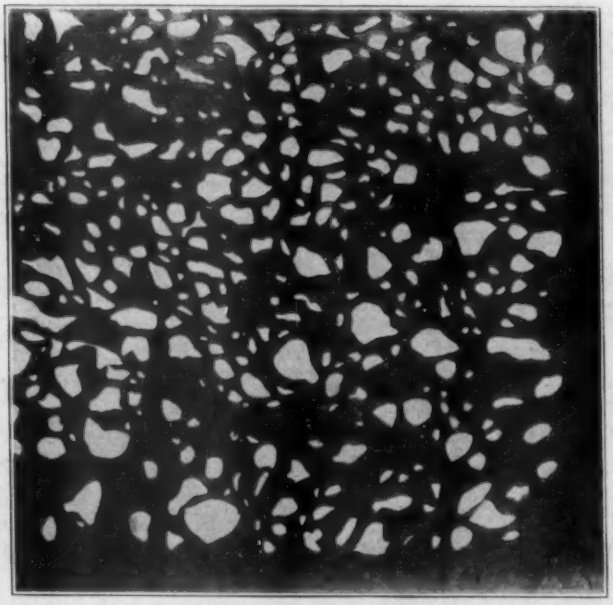

Fig. 3.—Negative wax plate of one section of the normal thyroid gland from which the inner lining of the traced epithelial follicles have been cut out. This area represents the group of follicles of one section of the series of microscopic sections the positives of which made up the wax model of the normal thyroid gland. The wax plate is 19.6 cm. square and 1.5 mm. thick. Reduced to × 18 from × 75.

of the wires were removed and the edges of the casts of the inside of the follicles were fused together and smoothed off with an electrically heated needle. The same technic was used in reconstructing the normal thyroid gland and the gland from the case of exophthalmic goiter. Photographs and drawings were made of the models before and after their completion (figs. 23 to 32).

As already mentioned, in order to study the morphology of the gland as a whole and the units or regions into which it is divided as well as the external form of the follicles, the method of maceration and microdissection was employed. Fresh glands, both normal and those from cases of exophthalmic goiter, were

placed in a macerating fluid which was first used by Siehler and later modified by Heuser.[2] That glandular epithelium becomes sharply delineated and connective tissue more transparent and swollen by acetic acid has long been known. The solution used by Siehler for macerating muscle and by Heuser[2] in his study of the uterine glands of the pig contained 5 per cent glacial acetic acid, 12 per cent glycerin, 1 per cent chloral hydrate and a diluted solution of formaldehyde U. S. P. (1 : 10), in an aqueous solution. This was employed in the present study. The thyroid tissue was fixed in this solution for three weeks, after which it was macerated for one hour at 60 C. in 5 per cent hydrochloric acid. The glandular epithelium would become white and opaque in the Siehler-Heuser[2] solution, while the connective tissue becomes swollen to two or three times its normal size, and more transparent. The consistence of the gland increases, so that the tissue is more firm and of greater stability for dissecting. The slight maceration in 5 per

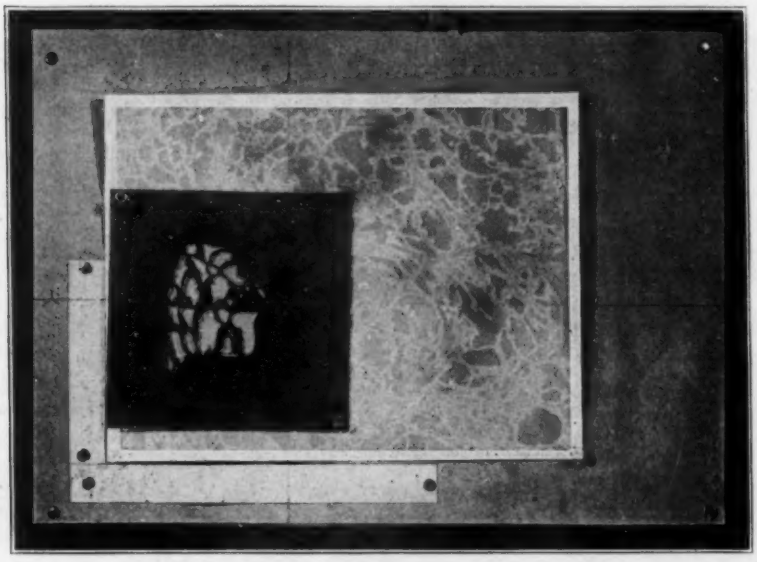

Fig. 4.—Negative wax plate in which the inner lining of the follicles has been cut out. This area represents the group of follicles which were enclosed in the fibrous septums, constituting the area from which the wax model of the exophthalmic gland was made. About the periphery can be seen the outline denoting the inner lining of the follicles in adjacent regions of the gland which were not included within the fibrous septums chosen as the peripheral limit of the model. The wax plate is shown pinned down on the bromide film, superimposed on the photograph in order to be certain that all of the follicles have been cut out correctly and none overlooked. The wax plate is 19.6 cm. square and 1.5 cm. thick. Reduced to × 14 from × 75.

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2. Heuser, Chester H.: A Study of the Implantation of the Ovum of the Pig from the Stage of the Bilaminar Blastocyst to the Completion of the Fetal Membranes, Reprinted from Contr. Embryol. Carneg. Inst. Washington **19**:229-243 (Aug.) 1927.

cent hydrochloric acid is just sufficient to soften the connective tissue encompassing the gland, thereby rendering subsequent dissection somewhat more easy.

The dissection of the thyroid was then carried out under the binocular dissecting microscope, with the tissue immersed in the Siehler-Heuser solution. The bottom of a glass dish 4 cm. deep and 11.5 cm. in diameter was covered with a layer of cork 1 cm. in thickness. The thyroid was placed in the dish and completely covered with the solution. It was then immobilized by means of silk tension threads drawn across its surface and fastened at each end in the cork by common pins. In this way the gland to be dissected could be held in any position for an indefinite length of time, the formaldehyde preventing decomposition of the tissue. The complete dissection of an entire right or left lobe and isthmus of a normal thyroid requires many months, not only because there is a great deal of work to be done, but also because one is not able to dissect for long at a time due to fatigue.

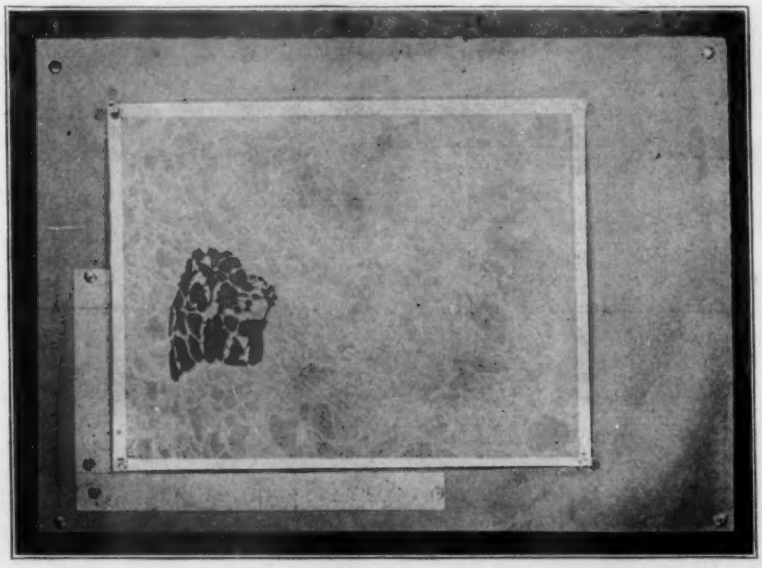

Fig. 5.—The group of follicles which have been removed from the wax plate shown in figure 4. This group has been wired together and superimposed on the corresponding bromide plate for corroboration of the position and grouping of the positive cast of the inner shape of the follicles for that section. Reduced to × 14 from × 75.

Somewhat to my surprise, a convenient differential staining reaction took place. As a result of the action of the iron pins, cork and Siehler-Heuser solution, the epithelial parenchyma of the thyroid became stained an opaque black gray, but the connective tissue and blood vessels were not affected and remained transparent and comparatively white. This facilitated the removal of the connective tissue and blood vessels because of the contrast in color, and also insured against the probable damage or removal of the parenchyma by dissection. This staining of the parenchyma was assumed to be due to the action of the tannic acid in the cork on the iron in the pins, as the Siehler-Heuser [2] solution alone did not seem to possess this quality. Sharp dissection was necessary because of the relative

firmness of the tissue, and to accomplish this, cataract knives of various shapes were ground down so that the blade of the knife was quite small. These were ground on a small (Arkansas) stone under the binocular low power, 55 mm. lens, which made it possible to minimize the serration of the edge of the blade. Needles and forceps were likewise ground down to as fine points as possible. Blunt dissection was of no avail after fixation in Siehler-Heuser[3] solution. A Spencer binocular microscope was used and for the entire lobe the 55 mm. lenses were found to give the optimal magnification, i. e., 44.4 times for dissection. Direct illumination from a 6 watt and 50 volt globe was used in an adjustable lamp. This could be focused and the light or beam concentrated, made more intense or more diffuse and thereby subdued, as desired. This flexibility of the beam was important because of difficulty in illuminating inaccessible areas or regions of the gland. A large amount of periglandular connective tissue was first dissected off the lobe and isthmus. This large amount of tissue was removed from the body with the gland in order to avoid injury to the thyroid. In the operative specimens as little damage to the gland was done as possible. Because of the differential staining, no difficulty was experienced in recognizing the smallest amount of parenchyma, even the thin edges of the platelike areas which seem to taper off into the connective tissue capsule. After the connective tissue and blood vessels (although they could not be recognized as such at this low magnification, it is presumed that nerve filaments and lymphatics were also components of this tissue which here is termed connective tissue) had been dissected away from the gland, large spaces and clefts remained which divided the parenchyma into many regions to be described later. In order to dissect into these crevasses and between and under these bars of parenchyma, resort was had to small radially arranged retracting silk threads fastened at one end by bent pin hooks into the parenchyma of the gland, and at the other by attachment to pins stuck in the cork. In this manner the parenchyma could be separated without damage by simply tightening up on the threads. Also the septums of connective tissue, which everywhere penetrated and divided the thyroid, could be followed and removed from the innermost regions and crevasses without breaking any of the connecting bands or bars of thyroid tissue. As the dissection progresses from the external surface of the gland to the interior it becomes increasingly difficult owing to the ramifications and the coral-like complexity of the gland which is more closely packed and interlaced in the deeper zones. The cleavage of the larger stalks and branches of connective tissue from the parenchyma is obtained with comparative ease, but dissection of the much finer strands of connective tissue binding together the individual follicles is far more difficult. The connective tissue septums of any considerable size are sufficiently macerated to render their dissection relatively much easier. By this method the morphologic structure of the thyroid as a whole can be demonstrated and the various regions into which it is divided can be identified. The tenacity of the interfollicular supporting tissue is illustrated by figure 7, which shows some of the fibers still clinging to individual follicles which were dissected away from a bar of thyroid tissue after maceration in 5 per cent hydrochloric acid only. These follicles were picked and plucked and rolled in petrolatum mixed with lampblack, but some of the connective tissue still remained adherent and could not be cleaned off. A portion of a fresh gland was macerated in 50 per cent hydrochloric acid for one hour at 60 C., but this procedure caused the follicles to break up completely, leaving only the colloid which was denuded of its epithelium. However, after fixation of the tissue for several weeks in a

diluted solution of formaldehyde U. S. P. (1:10), it can be macerated in 50 per cent hydrochloric acid for one hour at 60 C. and then the follicles may be dissected from the gland and each other with ease and contain the colloid within the epithelial sac. The thyroid tissue was transferred from 50 to 5 per cent hydrochloric acid for dissection. Very gentle dissection was imperative, especially with the thyroid tissue from the case of exophthalmic goiter, as the follicles are much more friable and more easily torn than the normal thyroid follicles. Porcupine quills held in fine glass tubes and the quill of the South American ant eater similarly held were found most efficacious as dissectors. Higher powered lenses were used than for the dissection of the entire gland. The tissue that was macerated and dissected for the study of the follicles was from the same gland that

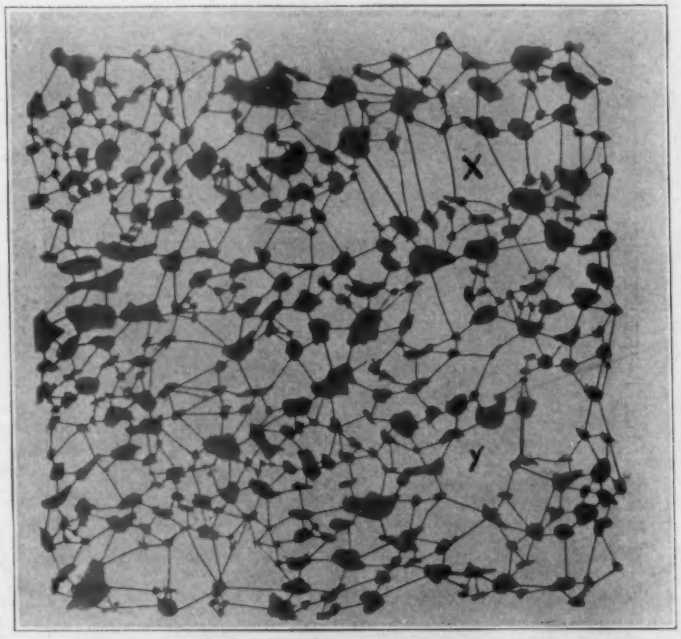

Fig. 6.—The positive cast of a bromide plate of the follicles of one section of the normal thyroid gland after they were wired together. The preponderance of small follicles in proportion to larger ones is to be noted. The course of the fibrous septums can be seen at *X* in the upper portion of the photograph and at *Y* in the lower portion. These can also be traced later in a more complete model shown in figures 23 and 24. Reduced to × 21 from × 75.

was used in the wax reconstruction. The entire follicle with the colloid, epithelium and the follicular capillary bed was dissected out. The latter could be removed if desired. A portion of the epithelium was frequently cut away so that one might look down into the follicle and perceive the inside of this unit much as in a kaleidoscope. This was particularly true of the follicles from the cases of exophthalmic goiter. As the follicles were dissected free they were cleansed by removing all the adherent tags of connective tissue, sucked up into a pipet and placed in a group in a glass dish containing 5 per cent hydrochloric acid and in

the bottom of which was placed a piece of black glass. The dish was then completely filled with the 5 per cent hydrochloric acid solution and covered so as to exclude all the air in the dish and also keep out lint. The dish could then be moved about without disturbing the grouping of the follicles. Subdued direct illumination was used, and the groups were photographed. Individual follicles were held in position under the solution by placing them in a small ring of petrolatum which was placed in a hollow-ground slide before the fluid. In this manner, alternate sides of a follicle could be photographed. These specimens were also stabilized so that they could be handled by excluding all the air from the hollow-ground slide by means of placing a coverslip on the slide, a large ring of petrola-

Fig. 7.—A group of follicles isolated by sharp dissection from a portion of the parenchyma of the normal thyroid gland after fixation in Siehler-Heuser solution for three weeks and maceration in 5 per cent hydrochloric acid at 60 C. for one hour. The follicles show tags of fibrous tissue which clung tenaciously. White areas in follicles represent portions of the wall composed by epithelium, which walls were thicker at that point than in the more clear areas where the walls were very thin and of the thickness of one epithelial cell only. The variation in size is typical of the normal gland, and the tendency for each follicle to be more or less spherical is also characteristic. The shiny colloid can be readily seen. Again the proportion of small follicles to large makes this a characteristic group for the normal thyroid gland; × 18.

tum having been previously run around the edge of the hollow depression and the fluid brought up to the edge of the ring. Specimens can be preserved indefinitely in this manner.

DESCRIPTION OF DISSECTED GLANDS

As already mentioned, previous investigators of the structure of the thyroid gland have confined themselves to so large an extent to description of the individual follicles, that the morphology of the gland as a whole and the manner in which it is subdivided have been left undescribed. In this report the structure of the gland as a whole will first be described and illustrated; this will be followed by the morphology of the regions into which the gland is subdivided, and lastly, by a detailed account of the follicle or definitive unit of the gland. Thus an orderly sequence is adhered to which reveals the entire

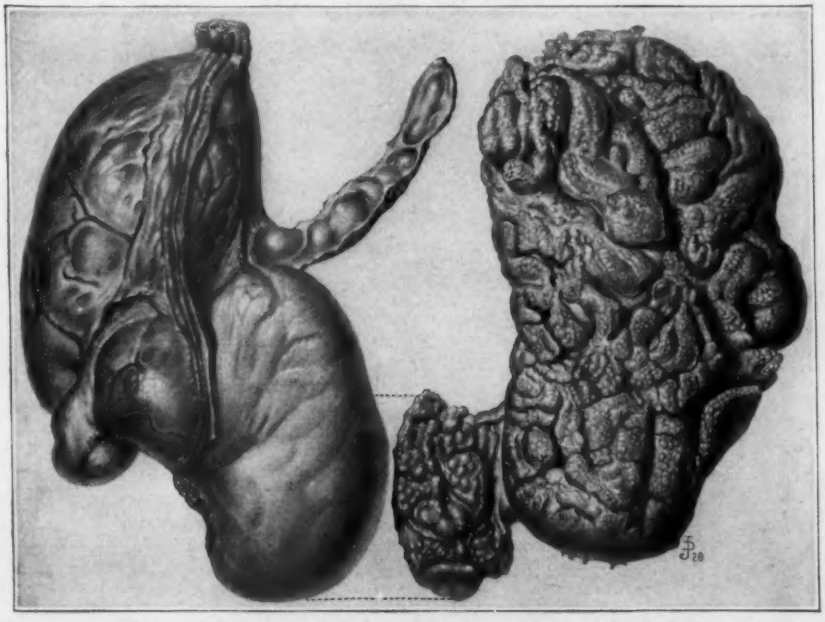

Fig. 8.—Normal human thyroid, right and left lobes together with the isthmus. The dotted line shows where the isthmus, which in the section was left attached to the left lobe, joins the base of the right lobe. The right lobe is shown covered with fascia as it was found in the cadaver. The anterior branch of the superior thyroid vessels is seen descending from the upper toward the lower pole. From the junction of the upper portion of the right lobe can be seen a bizarre pyramidal lobe. The isthmus and the left lobe are shown with all fibrous tissue investment, including blood vessels, nerves and lymphatics dissected away. It is to be noted that there are no true lobules but a complex mass of parenchyma irregularly divided by an intricate anastomosing system of spaces or channels forming within the gland a veritable fenestrated labyrinth. The gland as shown is made up of regions of connecting bars, bands or platelike regions composed of individual discrete follicles or acini. The stippled appearance of the surface represents the follicles; × 1.4.

structure of the thyroid gland. The normal gland and the gland in exophthalmic goiter are described and compared.

General Form and Subdivision of the Gland.—By employment of special fixation, maceration and microdissection, the connective tissue including blood vessels, nerves and lymphatics was dissected away from the entire left lobe and isthmus of a normal thyroid gland. In figure 8, the undissected right lobe of the same gland is shown for comparison. When the connective tissue investing the thyroid is removed with the blood vessels, lymphatics and nerves, the gland is revealed as a complex mass of tissue which is divided and irregularly broken up into many regions or areas of parenchyma.

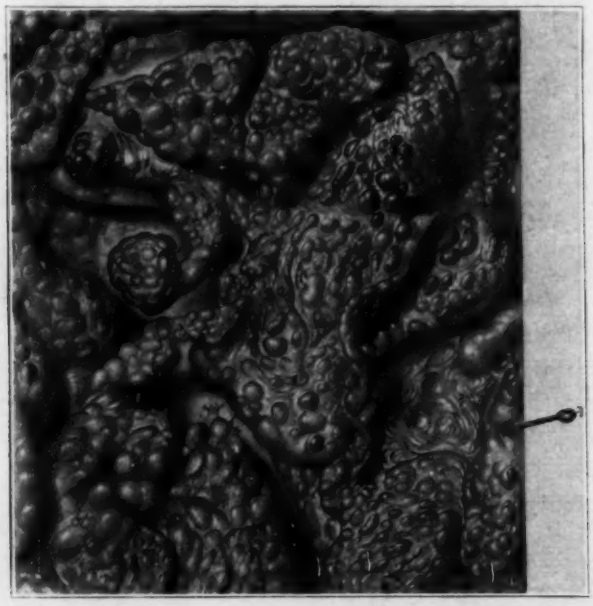

Fig. 9.—Normal human thyroid. Higher magnification of the anterior superior portion of the left lobe is shown in figure 8. Note the small hook to the right of the drawing which demonstrates the pin retractor used for separating crevasses of the gland. The various shapes of the parenchymatous regions are evident, varying from a triangular quadrangular area to that of a cube or almost perfect sphere. Reduced from a magnification of × 12.

These areas or regions of thyroid tissue are in turn made up of groups of follicles of different number, shapes and sizes depending on the shape, size and location of the region which these follicles compose. The form of these regions varies widely and is inconstant. Not only in the specimen depicted here, but also in other normal glands dissected this irregularity in form and size was noted. There seemed to be a total lack of uniformity not only between the various

subdivisions or regions of the same gland and lobes of the same gland, but also between various glands as portrayed by the different patterns shown on their surfaces. These regions or areas of the parenchyma of the thyroid may best be described as connecting or annectent bars, bands or platelike pieces of tissue. The entire lobe of the thyroid is irregularly traversed by septums of connective tissue carrying the blood vessels, nerves and lymphatics. In this manner the parenchyma is divided and subdivided into many regions which, as previously stated, have the greatest diversity in shape and size with but one constant feature; namely, that all these regions were joined to each other at one or more points and in no case was a portion of parenchyma so completely surrounded by connective tissue that it was isolated from

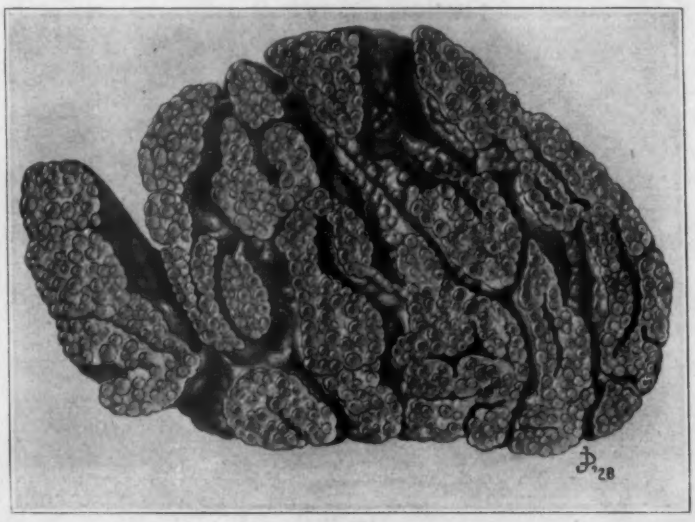

Fig. 10.—Cross-section of normal human thyroid. Cross-section of the superior anterior region of the dissected left lobe shown in figure 8 demonstrates anastomosing channels or spaces forming fenestrated labyrinth. It is to be noted that clefts do not completely traverse the gland; × 2.5.

the remainder of the gland. In some instances the annectent bar or connecting band of tissue between one region and another was only a small thin stem of parenchyma composed of a single row of follicles and their interfollicular supporting tissue, while in others the connecting stalk would be much larger in all dimensions and would approximate in size the regions which it joined together. After removal of the bands of connective tissue by dissection, the crevasses and spaces between the various regions of parenchyma extended throughout the entire lobe, forming a complex system of anastomosing channels ramifying throughout the gland and causing it to be broken

up and divided in an irregular manner, so that it formed a fenestrated labyrinth within the gland. The complexity and compactness of the coral-like arrangement of the parenchyma increased as the dissection was carried from the outside toward and into the inner zones. Unless great care is exercised in removing the outermost layers of connective tissue, a portion of the parenchyma may inadvertently be removed, for the relatively smooth convex surface of the thyroid is formed by broad, flattened, platelike areas of parenchyma which overlap each other much as do the feathers of a bird. The edges of these overlapping regions are thin, usually of the thickness of only one follicle. Probably as a result of the pressure of the contiguous structures in the neck, many of the surface regions of parenchyma become flattened and spread out with their connecting stalks or bars beneath the surface, giving the entire platelike region, in profile, the appearance of a mushroom or a palm leaf (figs. 9 and 10). The external flattening pressure is also reflected in the shape of the individual follicles which form the delicate overlapping edge, in that they are much thinner and more flattened than the follicles elsewhere in the gland. These tongues or edges of the flattened platelike regions of tissue forming the surface of the gland gradually blend with the connective tissue which invests the gland and become more attenuated until the plate ends by tapering off to a delicate point or nose composed of only a few follicles in a strand of connective tissue. Again, on the surface at the point of ingress or egress of the blood vessels, the delicate and prolonged end of a plate may be observed to have embraced the vessels and to be extending along their course for a short distance. Not all the areas of parenchyma presenting on and composing the surface of the gland are of the flat platelike variety, however, for some are distinct bars and bands in form, while others are spheroidal (fig. 9). There are all manner of gradations between these varieties of bands or bars and the spheroidal types of parenchymatous regions with no suggestion of uniformity. This point is well shown in figure 9. From this it can be seen that there are plates of parenchyma which on the surface appear triangular; others almost quadrangular, and others, again, almost perfect spheres. They are, of course, made up of a group of closely connected follicles, and all are connected with each other by some bridge, bar, band or fenestrated arm of thyroid tissue. In figure 9 an area is shown which is almost completely isolated from the surrounding parenchyma except for a narrow arm of tissue connecting the gland. If a section 10 microns in thickness had been cut through this spherical knob of the parenchyma of the gland either in a plane perpendicular to the gland or in one horizontal above the connecting arm, the false impression of a lobule of thyroid tissue completely surrounded by con-

nective tissue septums would have been obtained. The flattening of the surface plates is also well shown in figure 9.

The stippled appearance in figures 8 and 9 is caused by the follicles composing these areas of parenchyma. The higher magnification of figure 9 demonstrates this point more clearly. The open spaces or clefts often extend almost entirely through the lobe but are eventually

Fig. 11.—Photograph of group of follicles dissected from a normal human thyroid. Note the variation in size, also the marked transparency of some of the very small follicles. Compare with the more dense ones shown in figures 16, 17 and 18 which were dissected from the exophthalmic goiter. It is to be noted that the latter are much more white and dense due to the increase in amount of epithelium in proportion to the amount of colloid. The normal follicles are relatively spherical in shape with a smooth external contour. The white areas in the walls of the follicles are those in which the epithelium seems more thick and dense; × 6.7.

made to end blindly by connecting bands or bars which join one portion of the gland with another. Figure 10 is a drawing of a cross-section of the lobe shown in figures 8 and 9, and brings out clearly the tendency of the surface parenchyma to take the form of a flat, platelike structure with two more or less flat surfaces and an edge. The larger number of annectent or connecting bars and bands or stalks of parenchyma joining larger regions of the inner zone together is to be observed in figure 10.

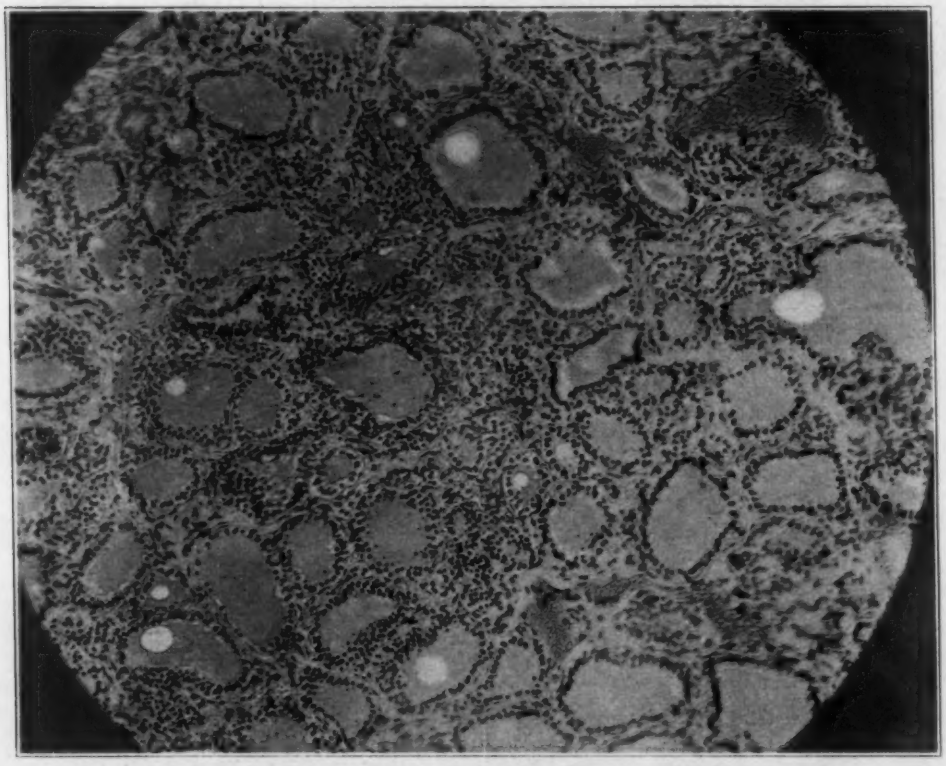

Fig. 12.—Microscopic section of normal human thyroid gland stained with hematoxylin and eosin. The follicles were dissected and the wax model made from same gland from which this section was removed. It is to be noted in this section that some follicles are cut through at their maximum diameter, while others are cut through at their minimum diameter. Some groups of cells shown between the larger follicles represent a tangential section through the dome of an underlying follicle. Thus, in any one section all the follicles are cut through at different levels, thus causing their diameters in a certain section to be entirely different. Follicles cut through their domes, so that the lumen of the follicle is not shown, give the impression of a group of interfollicular or interacinar cell rests; × 40.

As one progresses to the inner zones of the gland, the connective tissue septums are dissected away with a good cleavage from the parenchyma, leaving clefts and open spaces which twist and turn and penetrate the gland in all directions.

As mentioned before, the inner zone of the gland was more compact as well as complex than the outer zone. The parenchymatous

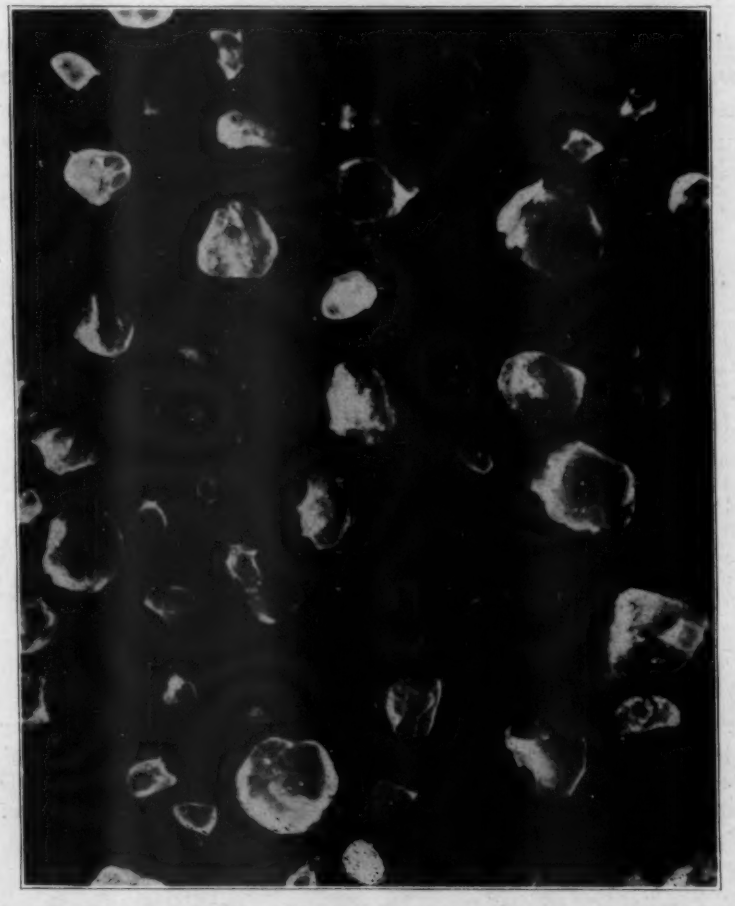

Fig. 13.—Group of follicles dissected from normal human thyroid. Spherical shape together with the variability and thickness of the epithelial wall as evidenced by the difference in the photographic shadow cast is well brought out. Points called attention to in legend of figure 11 are well shown in this figure; × 20.1.

tissue seems to occur less in the form of the flat plates seen on the surfaces, but more in the nature of large columns or trunks and bars. Again, this difference in shape of the larger regions of parenchyma was reflected in the forms of the individual follicles which will be described later. Also the connecting links between the areas of gland-

ular substances were much greater in breadth and thickness and perhaps better described as bands rather than bars. In the glands observed in this study there seemed to be a definite stratification to the thyroid. This was manifested chiefly by the tendency of the plates, bands and bars of parenchyma as well as the open spaces and clefts to be roughly parallel to the long axis of the body and the surface of the gland. This tendency toward a stratification is not present or reflected in the follicles. No uniform and distinct lobules were observed, and further, no areas of parenchyma completely surrounded by connective tissue occurred. The foregoing description of the maceration and microdissection of the normal thyroid applies also to the gland as a whole in exophthalmic goiter, except that the exophthalmic gland with the various subdivisions is larger.

Fig. 14.—Anterior view of follicles dissected from normal human thyroid including the surrounding capillary bed, showing the vessel of ingress and capillary distribution. The white arc about the periphery of the follicle is due to the reflection of the light shown down on the follicles by the convex edge of the epithelial wall; × 85.

The Individual Follicles.—The method of maceration and microdissection was particularly applicable to the study of the individual follicles of the thyroid in even a greater degree than to the morphology of the gland as a whole. By macerating the glands, after fixation in a diluted solution of formaldehyde U. S. P. (1:10), with 50 per cent hydrochloric acid, it was possible to dissect the most delicate follicular irregularities and the entire follicle with their anastomosing capillary bed without injury to either. The use of the quill of the porcupine and South American ant eater made possible the delicate separation

of the follicles from each other by perfect cleavage. The slightest tearing of these epithelial sacs was at once evident, and by dissecting so as to leave in situ the capillary bed, one could be sure that the wall of the follicle remained undamaged. The capillary plexus might then be removed, leaving the epithelial sac alone and intact. Furthermore, a break in the continuity of the epithelium allowed one to look down into the follicle, whereupon the torn epithelial edge could readily be seen and also the inner lining of the epithelial wall. The external form of the individual follicles was determined in this manner. The sources of error which are attendant on a wax reconstruction were eliminated by this method of investigation. In the studies of the individual follicles by previous investigators, and also, as will be pointed

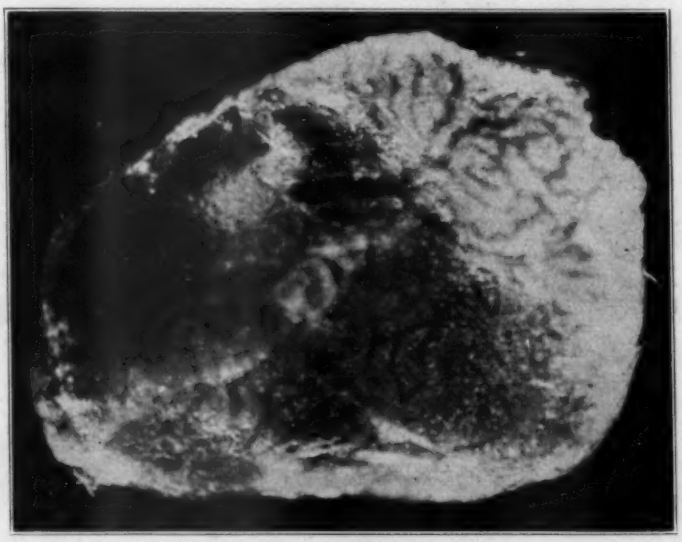

Fig. 15.—Posterior view of the same follicles shown in figure 14 to demonstrate the complete enclosure of the follicles within the capillary bed; × 85.

out later, in the present study, as far as the wax models were concerned, the inner margin of the epithelial lining of the follicle has been used as a criterion of the shape of the follicle. This resulted from the fact that the inner epithelial margin of the thyroid follicle is more easily defined microscopically and traced than the external margin. The latter is not infrequently difficult to recognize in stained sections and therefore does not readily lend itself to an accurate tracing onto the wax. The resulting model is a cast of the inside of the follicle and portrays the internal form, whereas the follicle dissected entirely free from its surroundings after maceration reveals its true and actual shape, size and external form. Figure 11 shows a group of follicles which have been dissected from a macerated specimen of a

portion of the normal adult thyroid gland, also from which the wax reconstruction was made. The dissection was made under the binocular microscope at a magnification of 20 times and photographed in a subdued light at a magnification of 40 times. The stained microscopic section of this gland is given in figure 12. A great many of these follicles were so small and transparent that they faded out in the negative. However, faint traces of some of them may still be seen which appear to be mere fragments of follicles in the photograph. The subdued light was shown directly on the specimen at the time of photographing. The high lights in the follicles shown are the areas in which the epithelium was more dense or thick. This density or thickness in the epithelium seemed to be due to slight infolding of the epithelial wall and also to an increase in the size of the individual cells. In the less dense regions of the follicle wall there was just a thin layer of flattened endothelial-shaped epithelial cells in which no infolding of the epithelial lining existed. The more transparent areas in the follicles represent, therefore, regions in which the walls of the epithelial sac are more thin and translucent. The follicles are full of colloid which transmits light readily and therefore does not show up well in the photograph, thus giving the follicle the appearance of a closed epithelial sac containing a clear substance which maintains the normal contour of the follicular unit. The follicle is a structure in which the epithelial walls encircle a colloid substance contained within so that when direct light is shown on this unit the margin appears in the photograph to be of greater density and the follicle is therefore more plainly defined or outlined. The more clear areas of the follicles shown in the photograph are the regions in which there is a thin sheet of epithelium of only one flattened endothelial-like cell in thickness enclosing the colloid substance. In some follicles, especially the smaller ones, the entire epithelial sac is composed of the most thinned out epithelial sheet in which there is no infolding of the epithelial wall or even an enlargement of the epithelial cells. In the photograph these transparent small follicles hardly cast enough of a shadow to be photographed and they therefore are not all shown. As seen in figures 11 and 13 there is a great diversity in the size of the follicles, but the outstanding characteristic of the normal thyroid gland, as will also be shown in the wax model, is the great preponderance of the small follicles over the larger ones. The normal follicles vary from 20 microns to 1 mm. in diameter, but relatively only a few attain a large size. the great majority are small and in many there was hardly a lumen. There did not seem to be any special distribution of the follicles in regard to size. The larger ones were evenly distributed throughout the gland with the smaller ones.

The shape of these units varied as much as did the size. There were no two follicles alike. The smaller ones more frequently approximated to a true sphere than the larger ones. However, they were all spheroidal, i. e., a solid body with the points in the circumference about equally distant from the center of the body. The epithelial walls in each follicle encircled the colloid substance and there were all forms and shapes from that of a perfect sphere going through all stages of

Figs. 16, 17 and 18.—Dissection of group of follicles from gland of a patient with exophthalmic goiter. Figures 16 and 17 are from the same gland from which the wax model was made, while figure 18 is from another gland. Note the variation in shape and size of the follicle, also the increased definition and density of the follicles due to the proportion of increase in epithelium to the colloid. The magnification of each illustration is × 6.7.

globular, oblong, triangular, cuboidal, hexagonal, octagonal, to that of almost a perfect cube. Some follicles were slightly faceted from pressure and others the least bit cupped on one surface because of resting on the dome of an underlying follicle, but on the whole the general form tended to be that of spheroidal with a tendency of the

follicle wall to be tapered off to a point at two or more areas, usually rather remotely situated on the follicle. The outside wall of the epithelial sac except for the facets, cupping or gentle tapering was essentially smooth. There were no pseudopodial outpouchings of the wall, nor regions showing constriction or budding of a primary into a secondary follicle. All the major irregularities in the epithelial wall

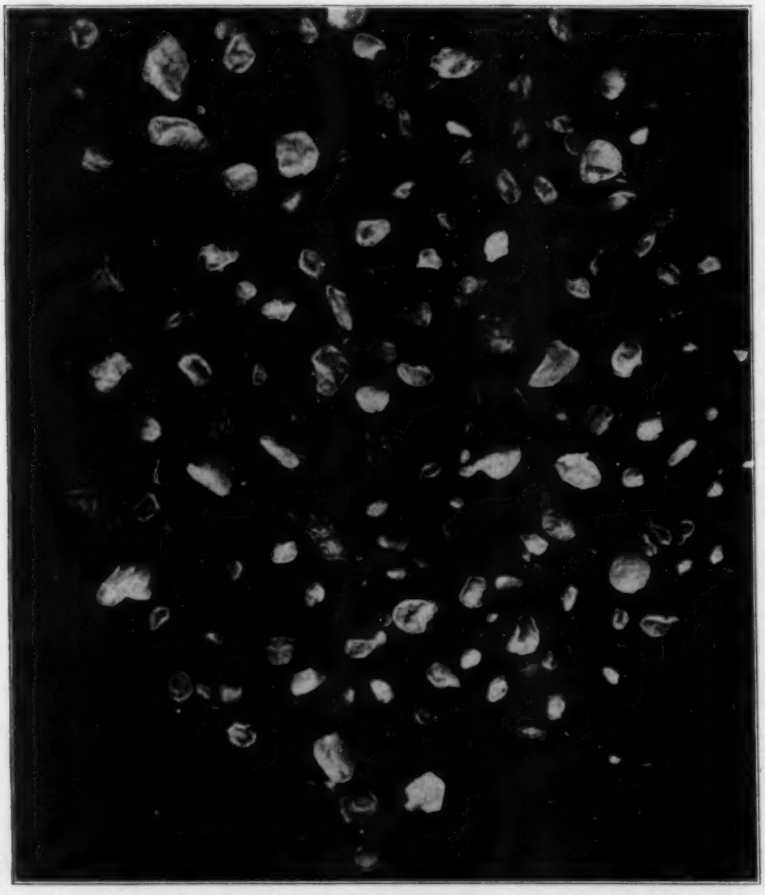

Fig. 17.

occurred inside the follicle, that is, internally and not toward the outside or externally. This will be more clearly shown when the follicles of the exophthalmic goiter are discussed. No junction or branching of any follicles occurred. They were entirely discontinuous and separate individual units. No evidence of any tubes or tubular formation could be observed. Small follicles would be grouped about the larger ones, but they always were dissected away with excellent cleavage and com-

plete separation, there being no continuity between the small and the large follicles. The roundness of the follicles and their rather symmetrical appearance gave the impression that they were completely filled with colloid, whether small or large, excepting the small ones in which there was scarcely a lumen, and that there was plenty of room in the gland for each follicle to become normally distended without

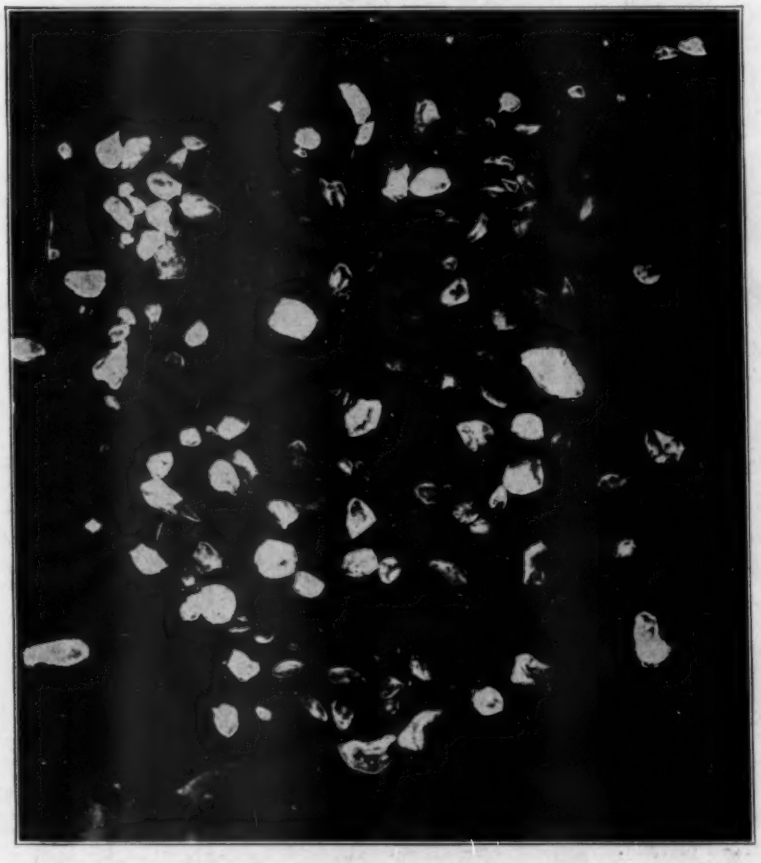

Fig. 18.

causing changes in the shape of each other by pressure. The follicles, though varying in shape and size, were all complete, distinct and fully differentiated histologic units. If the presence of colloid is an indication of function, then the larger follicles were carrying on the major part while the smaller ones were being held in reserve. It is highly improbable that a gland functions throughout its entirety at the same time. No evidence of any undifferentiated epithelial cell rests was made out from the maceration and dissection of the gland.

As has been said, the fibrous tissue capsule of the thyroid gland with the blood vessels and connective tissue septums were dissected away with great ease after fixation in Siehler-Heuser [2] solution and macerated in 5 per cent hydrochloric acid for one hour at 60 C. However, the follicles which collectively formed the parenchymatous tissue were bound together in close union by an interfollicular connective tissue which carried in its framework arterioles, capillaries, venules, lymphatics and nerves. This interfollicular connective tissue was much more difficult to dissect off from the individual follicles. There was no cleavage such as occurred in the removal of the main septums which divided the gland into many regions. The follicles could be dissected

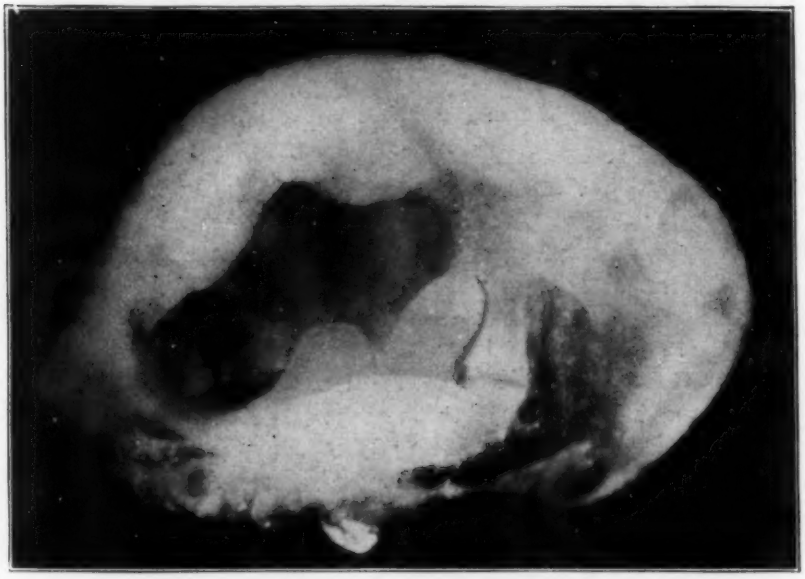

Fig. 19.—Isolated follicles from the exophthalmic gland from which the wax model in figure 32 was made. Note the smooth external contour and irregular internal surface. The clear area represents colloid into which finger-like prolongations of internal epithelial lining are protruding; × 86.

away from a portion of a main region of the gland, but such sharp dissection with some force always endangered the follicles. Figure 7 represents a few follicles dissected in this manner in which the tags of connective tissue are still clinging to the follicles in spite of many attempts to clean them. So tenacious was this interfollicular connective tissue that a much stronger maceration was required and 50 per cent instead of 5 per cent hydrochloric acid was employed for one hour at 60 C. The more gentle blunt dissection then sufficed not only delicately to separate the follicles from each other, but also even to dissect

the capillary bed with the follicle. Figures 14 and 15 show the anterior and posterior views of the same follicle about which the injected capillary bed may be seen. On the one side is seen the vessel of ingress, and on the opposite side there is a similar appearing vessel. The anastomosing capillary bed invests the follicle completely. The apparent marginal gaping seen in figure 14 is due to the reflection of the light. Although not shown in this figure, the capillaries extend all around the edge of the specimen. The vascular bed about the follicle of the normal thyroid gland is thus shown to be very rich.

The Hyperthyroid Gland.—As previously mentioned, dissection of the tissue from the glands of patients suffering with hyperthyroidism or exophthalmic goiter was made simultaneously with that of the normal thyroid gland. The same technic was employed. Figures 16, 17 and 18 represent three different groups of follicles. In figures 16 and 17, the groups are from the same gland from which the wax model was made, while, in figure 18, they are from another gland. As happens in the normal gland there is great variation in shape and size of the follicles, but the follicles are on an average much larger in the gland from the case of exophthalmic goiter. The proportion of small to large follicles is definitely less in the exophthalmic gland than in the normal one. There are some follicles that are below the average normal size, but these are comparatively few. The groups of dissected exophthalmic follicles shown here are magnified 40 times and when compared with figure 11, which shows the normal group at the same magnification, it is readily noted that the average size of those of the

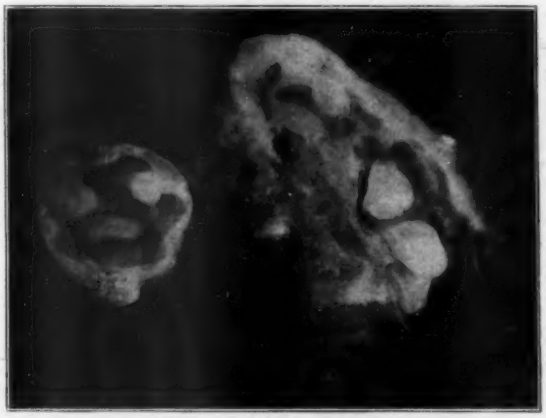

Fig. 20.—Saucer-shaped exophthalmic follicles dissected from the same gland as those in figure 19. The clear area represents colloid. Note the smooth external contour and irregular internal surface. The finger-like epithelial processes protrude into the lumen of the follicle; × 86.

normal gland are definitely smaller. The more sharp definition of the exophthalmic follicles in the figures 16, 17 and 18 is interesting because the density or thickness of the epithelial walls of the follicle is directly responsible for the definition on the photographic plate. The epithelial walls of the exophthalmic follicles are all more dense and thick than the normal by virtue of the fact that the epithelial cells are columnar or cuboidal and in most follicles the epithelium is infolded into the lumen of the follicles. The increase in opacity is readily appreciated by comparing figure 11 with 16, 17 and 18. The size of the follicles varied as compared with the normal from 0.21 to 5 mm., showing that the variation in size of the exophthalmic follicles is much greater than that of the normal, as is also the average size. If these larger follicles of the exophthalmic gland were distended with colloid, as are the normal follicles, to the limit of their epithelial lining they would be even larger in size. The present increase of the size of these follicles seems to be chiefly one of an increase in the amount of epithelium since there is little colloid present. The total epithelial surface as well as the amount of epithelium present seems to be definitely increased. The colloid, of course, is diminished. The increase in the size of each individual follicle due to an increase in the epithelium results, in exophthalmic goiter, in an increase in the size of the gland due to an actual growth of the epithelium or parenchyma. The second departure from the normal noted in the exophthalmic follicles was in the shape. Here again, as in the normal gland, the shape of each follicle differed in some slight degree. No two were alike. The various shapes and forms encountered will be appreciated by a reference to figures 16, 17 and 18. In these all variations may be seen, from a long straight cylindric tube to a perfect sphere, and again from a cube to a hexagonal, octagonal, globoid, hatchet-shaped or pear-shaped unit. Near the center of figure 17 will be seen a delicate, straight, almost y-shaped, tubelike follicle and to the left of the figure a follicle the shape of the figure six. These and the straight cylinder were the only types of tubular follicles encountered in this study. There is a definite difference, however, in the shape of the exophthalmic follicles when compared with the normal. This difference is shown only poorly by the photographs, and really to study it one should move around the follicles under the binocular microscope. In figures 16, 17 and 18 the broad side of the follicles has been photographed, as narrow ones could not be made to balance on an edge. For this reason the thickness of these exophthalmic follicles is not brought out in the photographs. The follicles did not seem to have room for proper expansion in the exophthalmic gland as they had in the normal gland and were more flattened against each other, their long axes being parallel to the surface or long axis of the plate, bar or arm of parenchyma of which they formed a part. In this

sense there was a stratified arrangement of the follicles of the thyroid but the stratification is different for each distinct region. After dissection it was observed that these follicles were not completely distended with colloid but appeared to be only partly filled with a less viscid material which allowed their walls to bulge less than those of the normal follicles. The follicles from the surface of the gland were disposed to be more flat and saucer-shaped, while the ones from the inner zones of the gland were more apt to be elongated or even more spherical or spheroidal. The shape of the follicle is therefore dependent to a great extent on the region or zone of the gland from which it comes. The tendency toward flattening and also elongation in the exophthalmic follicles constitutes the chief difference between them and

Fig. 21.—Camera lucida drawing of isolated exophthalmic follicles, showing smooth external contour with very irregular internal surface. The thin epithelial roof or dome of this follicle is shown by the high lights, while the watery-like colloid inside the follicle is represented by the dark areas. Finger-like epithelial budding into lumen of epithelial lining is readily seen; × 40.

the normal. It is to be noted that except for the minor irregularities in contour the external surfaces of the follicles of the exophthalmic gland are relatively smooth and as observed in the normal follicles there are no pseudopodial outpouchings of the epithelial sac, no budding off of new follicles, no constriction or cleavage of the primary into secondary follicles. Grouped about the larger exophthalmic follicles are usually to be seen small satellite follicles which, if a section was made across them, might appear to be the result of outpouching of the follicular epithelial sac. This is only an illusion, however, for these small, peripherally placed follicles are in no way connected with the larger more central follicle. The follicles are definitely increased

in size but are fully differentiated and developed individual and independent units. There was no continuity observed between them.

Figure 19 is a photograph of a follicle from the gland of a patient with exophthalmic goiter. By means of a finely ground pair of scissors the top or dome of this follicle was cut away so that one might look down inside. It is to be noted that the external form is almost perfectly smooth, whereas the internal surface is irregular as a result of the infolding of the epithelium. The finger-like epithelial projections

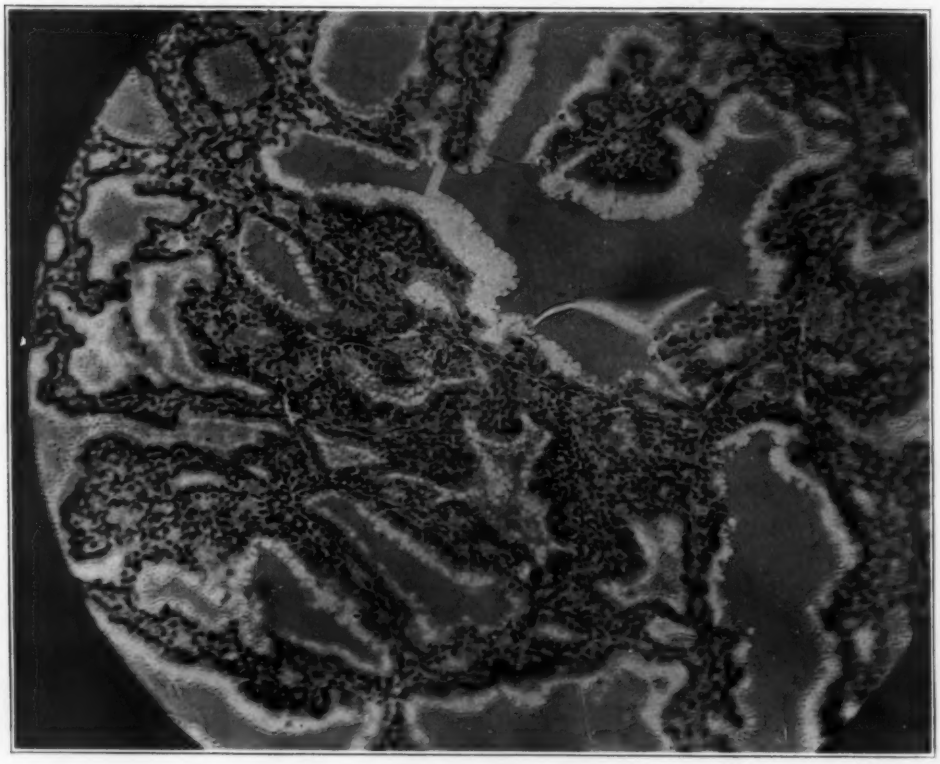

Fig. 22.—Microscopic section of the exophthalmic gland from which dissection and wax models in this study were made. Section shows papillomatous infolding into the follicles in one plane while the dissected isolated follicle shown in figure 21 represents the internal and external form of the follicle in all dimensions and is more of a stereoscopic view of the papillomatous infolding; × 40.

may be seen extending from the bottom epithelial rim toward the top where a very much thickened and irregular wall of epithelium exists. The right end of the follicle also shows a much increased epithelial covering. The clear area into which the papillomatous infoldings occur is the water-like colloid, the viscidity of which has been much decreased from that of the normal. This follicle is spheroidal. Figure

20 shows two saucer-shaped exophthalmic follicles from which the dome has also been removed. One looks down on them with the watery colloid covering the more opaque epithelial walls. Protruding up from the bottom may be seen several finger-like projections of the infolded epithelium. The external contours of these follicles are observed to be regular; the internal surface is very irregular. Figure 21 is a camera lucida drawing which accurately portrays the appearance of a single exophthalmic follicle. The relatively smooth external contour is to be noted in comparison to the very irregular internal surface. The thin

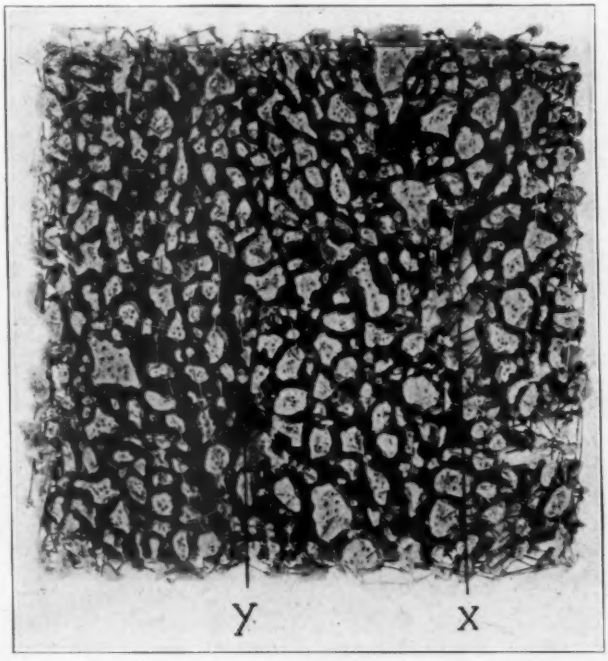

Fig. 23.—Top view of the half completed wax reconstruction of the normal thyroid. In the upper portion of the photograph can be seen the space corresponding to the fibrous connective tissue septums labeled *X*, and just below the middle on the right hand side is the course of another fibrous band labeled *Y*. These correspond to the similar tracts shown in figure 6. Reduced to × 21 from × 75.

epithelial roof or dome of this follicle is shown by the high lights and the dark area within represents the thin watery-like colloid into which the numerous buds or pseudopodial processes of epithelium have protruded. A section through the tissue of the same gland from which they were dissected is shown in figure 22 and the wax model to be described later was also made from the same gland. A comparison is in this way offered between a stained section of the follicle in exophthalmic goiter portraying the papillomatous infoldings in one plane and the dissected follicle showing the external and internal forms in

all dimensions. The study of the follicles by this latter method is obviously more accurate, affords a much better conception of the size and shape, the external and internal form with its blood supply than any other method heretofore employed.

RECONSTRUCTIONS IN WAX OF THE NORMAL THYROID AND THE GLAND IN EXOPHTHALMIC GOITER

In a review of the reports of previous investigators, it is interesting to note the influence of the technic employed in examination of the thyroid gland on their opinions and conclusions. In the early studies

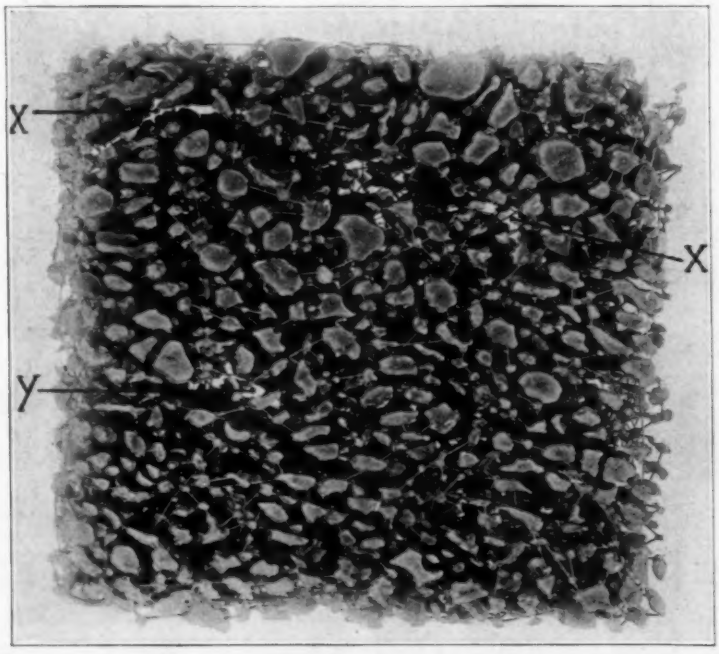

Fig. 24.—Top view of fully completed model before the removal of wires subtending the various follicles; × 21.

erroneous conclusions were arrived at because only an examination of the individual sections was made. This stage was followed by the use of graphic reconstruction and then the more accurate wax plate models were constructed. In this study wax plate reconstruction was employed when the problem was begun three years ago, but it was soon recognized that while certain points of interest could best be shown by this method, there were others which could not be determined. The limitations of this technic will be pointed out in the following description of the models and also later in this paper.

The technic employed in the formation of the models has been discussed in detail and need not be repeated here. The wax models

were made in order to determine, if possible, the presence of a true lobulation of the gland as a whole; the manner in which the gland as a whole was subdivided; the ramifications of the fibrous tissue septums; the size, shape and spatial relation of the follicles; whether or not the follicles were connected or were discontinuous; the presence of interacinar fetal cell rests, and the distribution of the capillary circulation of the follicle. In spite of the fact that both the model of the normal thyroid and that of the exophthalmic gland were the largest which have ever been reconstructed, it was impossible by this technic to determine all of these points, and particularly that of the structure of the gland as a whole and the manner into which it is subdivided. The microscopic areas of the sections to be reconstructed were selected from two different points of view. In the normal gland the right angle edges of the section, and therefore their photographic plates, were used

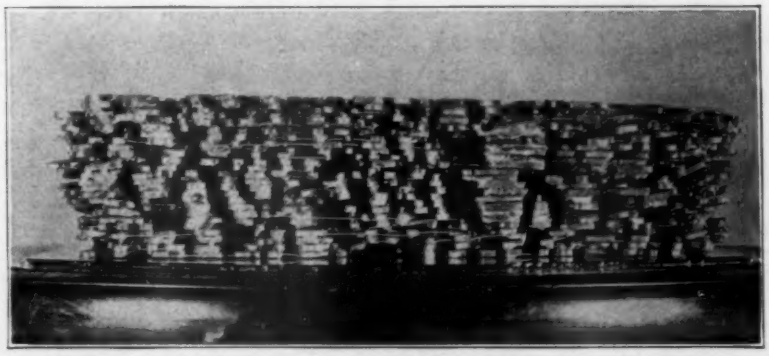

Fig. 25.—Profile view of the untouched model of the normal thyroid gland before the removal of wires. The great preponderance of small follicles may be seen in figure 25 as well as in figures 23 and 24. Largest follicle in entire model is shown in this photograph just to the right of the midline; × 21.

as the guiding points for the reconstruction of a large corner area of the microscopic section. This area was marked off by the lines of orientation, and all epithelial structures as well as fibrous tissue septums which occurred in this area were carefully traced on the wax plates. In this way any tendency to lobulation of the parenchyma could be disclosed. Further, all epithelial structures in this large area were reproduced in wax in their natural spatial relation to each other so that the presence of any interacinar epithelial cell rests would be evident. This complete reproduction in wax of a large area was felt to be more convincing of the true detailed structure of the parenchyma and its constituent follicles with their relation to one another, than the reconstruction of just a few individual follicles as had been done in the past.

In the gland of the exophthalmic goiter, however, the microscopic field from which the model was to be made was selected in a different manner from that utilized in the case of the normal gland. In this instance the selection was made with special regard to a microscopic area in the middle of a section, midway in the series, an area which was apparently completely circumscribed by connective tissue septums and which was also apparently a separated and isolated lobule of the parenchyma of the thyroid. The orientation lines were, of course, drawn as for the normal thyroid, but the fibrous connective tissue septums which apparently completely surrounded the area of parenchyma served as the marginal guides of the tracings on the wax plates, and therefore, the boundaries of the model of the exophthalmic thyroid tissue were formed by the connective tissue septums. The external form of the model portrays the course of these septums within the gland. Only the follicles contained within the boundaries of this fibrous connective tissue were reproduced in this model of the thyroid in exophthalmic goiter. In this way the connection or junction of the parenchyma enclosed within the fibrous septums with the parenchyma of another portion or region of the gland would be evident. Therefore, any separation, fenestration or attenuation of the fibrous septums would be manifested in the wax model by the tendency of the follicular parenchyma to break or protrude through the connective tissue envelope. This, as will be shown later, occurs in the model of the exophthalmic goiter gland. Thus the models differ in size and shape because the margins of the normal model were formed first by the right-angled edges of the section which bound the corner area of the microscopic field selected for reconstruction; and secondly, by the opposite edges of the wax plate cut at right angles, and on which the tracings were made. In this way an almost perfect square model was obtained which is a reproduction of all the structures, epithelial and connective tissue, that occur in a specific blocked-out microscopic area of the section, without any particular reference to the fibrous tissue septums, whereas the model of the thyroid from a case of exophthalmic goiter is a reconstruction of the parenchyma with specific reference to the fibrous septums of a certain microscopic field, and the external shape of the model depends on the course and ramification of these septums. It is, therefore, not a square model, but has more of a tendency to an asymmetrical tubular form. The magnification is the same in both models, i. e., 75 times.

Model of the Normal Gland.—The wax model of the normal thyroid will be described first. For the sake of clearness it may again be said that the model was made by tracing each microscopic section on a wax plate, from which tracings the models of the follicle were cut out and wired together as shown in figure 6. These positive reproductions were then piled on one another according to the lines of

orientation. Thus positive wax models were made of each and every one of the stained serial sections. The positive models were piled on one another according to their lines of orientation to avoid any distortion of the model. A view of the top of the wax reconstruction when only half completed is shown in figure 23, and in figure 24 the same view of the fully completed model. Figure 25 shows a profile view of the finished model of the normal thyroid before many of the wires were removed and also before the wax casts of the follicles were smoothed off with an electrically heated needle and fine spatula.

In figure 6, although this is a wax reproduction of one section only, the preponderance of small follicles to larger ones is already evident and their average in diameter, shape and spatial relation could almost be predicted from this section. The course of a fibrous connective

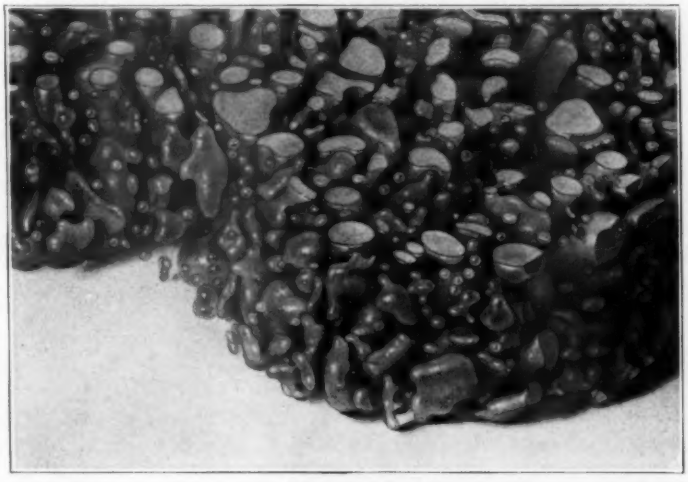

Fig. 26.—Drawing to scale of the wax model of the normal human thyroid. The model represents the internal shape of the follicles. The subtending wires are not included in the drawing. In the lower right corner may be seen one of the square sides of the model identified by the vertical or sagittal flattening of the incompleted follicles. Also the top of the model shows the incompleted follicles. The serpentine front is shown which represents an undamaged surface of the model and one including only completed follicles. This front was obtained by dividing the model along the course of the fibrous septums shown in figures 6, 23 and 24. Note the irregularity of the internal shape of the follicles, apparent budding, constriction and fission of the follicles. Also note the predominance of small follicles. It is at once evident that if sections were cut through this model at different levels some of the follicles would be sectioned at maximum and some minimum diameters. It is probable that sections through some of the smaller follicles or the dome of an underlying follicle might be misinterpreted as interfollicular or interacinar cell rests; × 45.

tissue septum can be seen in skeleton outline at the point *X* and, as will be shown, can be traced through the entire model. In looking at the wax reproduction of one section it is, of course, impossible to tell the cross-section of a very small follicle from a tangential section through the dome of an underlying although larger one. In figure 23, the wax model is only half completed. The course of the fibrous septum referred to in figure 6 can be traced in this model in the upper portion of the photograph. It is also labeled *X*. Just below the center there is shown the course of another fibrous band, labeled *Y*. The same division of the parenchyma by connective tissue can again be traced in figure 25, a photograph of the model after completion. The long septum *X* to the right side of the photograph and the shorter one to the left show up more clearly in figure 24 than in figure 23 because the former was photographed on a white porcelain plate, the latter on a plain glass plate.

Fig. 27.—Wax model of a single section of exophthalmic goiter. Comparison with figure 6 from the normal gland demonstrates the great difference in size and diameter as well as shape of the follicles in exophthalmic goiter as compared with normal thyroid gland; × 30.

Figures 23 and 24 furnish an idea of the model in cross-section showing again the great preponderance of small follicles in comparison to the larger ones and their complete discontinuity in this horizontal plane. The small holes in the surface of the follicles in figure 23 are due to punctures with an electric needle made while fusing each successive layer so that some of the connecting wires might be removed. In figure 25, a profile view of the model, the preponderance of the many small follicles is again shown. The supporting wire of each individual plate remains. In figure 25 the largest follicle of the entire model is seen. It may be traced through all but a few sections of the block and is greater not only in length but also in width than any of the other follicles. The discontinuity of the follicles is again demonstrated in the vertical plane. Figure 26 is a drawing to scale of the

completed model of the normal thyroid gland. All but a few wires were removed with a pair of electrically heated forceps and the few remaining were eliminated from the drawing by the artist, Mr. James F. Didusch. It will be noted that the drawing is made at an angle which shows the top of the model and also the now serpentine margin in front with just a small portion of one of the square sides of the model in the right corner of the drawing. The tip end of this straight side can be identified by the vertical or sagittal flattening of the incompleted

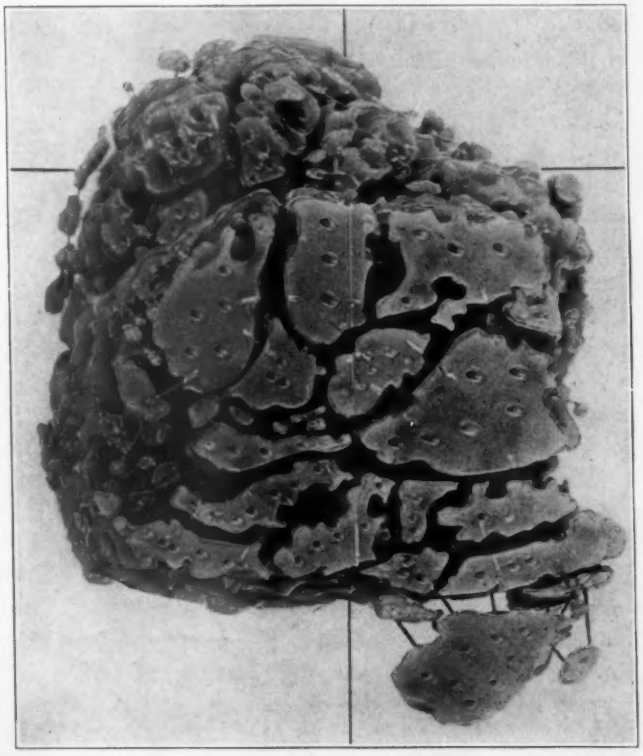

Fig. 28.—Top view of a half completed model of exophthalmic goiter. Note the irregularity in shape of the individual follicles; × 42.

follicles along the edge of the model. The drawing was made in preference to a photograph because three sides or surfaces could be portrayed by it. In order to present an undamaged surface of the normal gland and also a surface in which no incompleted follicles would occur, as shown in the straight cut surface in the right corner of the drawing, the model was divided along the course of the fibrous septums *X* shown in figures 6, 23 and 24. This division resulted in the formation of the serpentine front to the model shown in figure 26 composed of only completed follicles. It will also be noted that the wax

casts of the internal shape and form of the follicles shown in figure 25 have been smoothed off in figure 26. This was done partly because of the better and more clear definition of the follicles in the model after smoothing and also because the stair-step-like overhanging edge of the tracing of the follicle in each section is in reality an inaccuracy and should be removed. This fusing and smoothing out of the individual wax models of the follicles was accomplished by means of electrically heated needles and spatulas. In order that no errors should occur, constant reference was made to the stained sections and photographic plates. The great number of small follicles in proportion to the larger ones is at once evident, and this fact is made more striking when the illustration of the model of the normal thyroid is compared with that of the gland in exophthalmic goiter. It is to be recalled that the wax models of the follicles represent the internal form or shape of the follicle because the inner margin of the epithelial sac composing the follicle was traced on the wax. In this cast the internal shape of the follicle may be compared with the external shape demonstrated by the dissection of the entire unit as shown in figure 11. The internal shape of the follicle is more irregular and less spheroidal than the external form which is, of course, due to the infolding of the epithelial wall into the lumen of the follicle. The smaller follicles seem to be much more regular in form, being spheroidal. There are occasional casts of a distinct tubular shape and some that branch slightly, as can be seen in figure 26. There are also follicles that seem to give off buds and others that are constricted, but again it is to be recalled that these casts represent only the internal form of the follicle and not the external. Almost all varieties of shape are to be seen in the model, but when compared with the dissected specimens the much greater tendency to tubular form, branching, budding and constriction is evident in the model. The greatest variability in size is shown, from follicles 1.5 mm. or even less in diameter up to 35 mm. There is complete discontinuity of the follicles. No coiled tubules were encountered in the normal gland. No sign of junction between the follicles could be detected. The spaces between the follicles appear greater in the model than they actually are in the gland because only the inner margin of the epithelial wall was traced, and consequently the thickness of the follicle wall is lost in the model. The remaining space is normally filled with blood vessels, connective tissue, lymphatics and nerves. No evidence whatsoever was educed in regard to so-called interacinar fetal cell rests. There are no epithelial cell rests of any type in the normal thyroid gland of the adult. The only epithelium encountered in the thyroid was a fully differentiated variety which formed a definite part of the parenchyma; even in the smallest follicles

in which a lumen is scarcely visible the epithelium is arranged in the usual manner of thyroid epithelium and appears to be fully differentiated. It is obvious from figure 26 that if serial sections were cut through the model some follicles would be cut through at their maximum diameter while others would be cut tangentially only across their dome without even disclosing the lumen of the underlying follicle. This, of course, would give the impression of a group of interacinar cells apparently disconnected from the remaining parenchyma of the thyroid but would only be an illusion, for if the continuation of the series is followed it will be found that what appeared to be an isolated group of interacinar epithelial cells was merely the dome of an underlying follicle. In some instances, when the follicle is almost a true sphere in which the diameter is only 20 microns or even less, a series of sections 10 microns in thickness may be necessary to prove the follicular arrangement of the lining epithelial cells. In this study the serial sections of 20 microns in thickness were used to determine this point, and also for the reconstructions in wax; in addition, a series of sections cut 10 microns in thickness was studied for the presence of interacinar cells not a part of the parenchyma. The casts of the follicles of each section and the model as well were carefully checked with the serial sections in the series cut 20 microns in thickness to avoid the error of overlooking possible epithelial rests and clusters of interacinar cells. A graphic microscopic study was made of the other series of sections cut 10 microns in thickness, but not the slightest evidence was educed from either series even to suggest the presence of undifferentiated or differentiated epithelium between the follicles and not connected with, or a portion of, the parenchyma of the thyroid.

Even though the model shown in figures 23 to 26, inclusive, is the largest wax reconstruction ever made of the normal thyroid gland, it is at once evident that the structure of the thyroid as a whole and the manner in which it is subdivided into various regions cannot be learned from such a small area of the gland. Investigators in the past, some working only from single sections, others with very small models consisting of only a few follicles at an unnecessarily high magnification, have unhesitatingly described the thyroid as a lobulated gland. The structure of the gland as a whole and the form of its many subdivisions could not be learned from this model of the normal thyroid gland, simply because the block of tissue from which the serial sections were cut was far too small for this purpose. It is interesting to note that although this model is a complete reproduction of a much larger microscopic field than heretofore has been reconstructed in wax, and at the same time is the only model in which all the follicles of a given area have been included, yet it is impossible to discern any tendency

toward lobulation of the gland. Previous reports, although based on much smaller models of only a few of the larger follicles, overlooking the smaller ones, however, have concluded that the gland is definitely lobulated.

The Thyroid in Exophthalmic Goiter.—In the wax plate reconstruction of a portion of the thyroid gland from a case of exophthalmic goiter the same technic was followed as described for the normal gland.

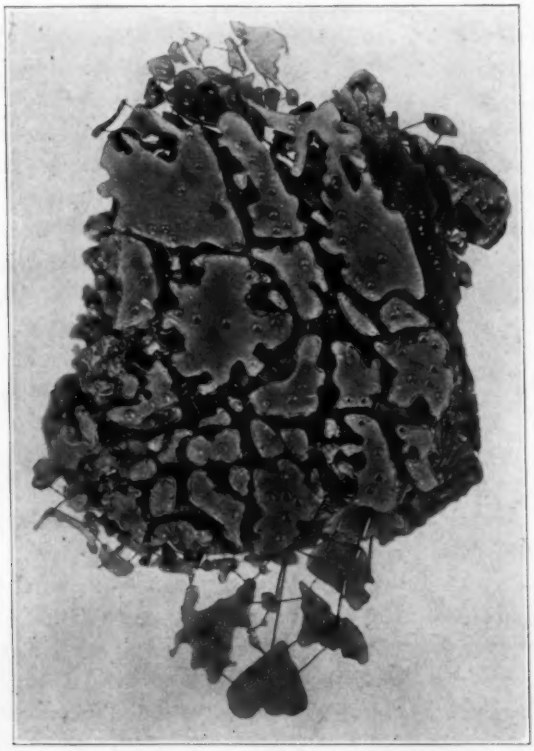

Fig. 29.—Top view of completed model of exophthalmic thyroid; × 40. Compare with figure 28.

The only difference lay in the method of the selection of the microscopic field for reproduction in wax. An area was chosen which apparently consisted of a group of follicles completely surrounded and isolated by fibrous connective tissue. This area was similar to those which in the majority of textbooks on histology are referred to as a "lobule." Furthermore, this microscopic field was located in a section toward the middle of the series so that one could build up or down in the series and follow this localized area through to its conclusion. Figure 27 is a photograph of the microscopic field reproduced on a bromide plate

transposed into wax casts of the follicles enclosed in the fibrous septums. The latter were not included in the tracing onto the wax, but all the follicles enclosed were included so that the external form of the model corresponds to the course of the fibrous envelope in the substance of the gland. In this way any tendency on the part of the fascia to become attenuated and fade out or to disappear into the surrounding parenchyma is evident in the sections and manifested in the model by the widening or spreading out of the original follicular grouping into a larger or rather branched group. The original small group of follicles circumscribed by the fibrous septums would become connected with contiguous parenchymatous areas; the latter in turn incompletely enclosed between other fibrous connective tissue bands would form con-

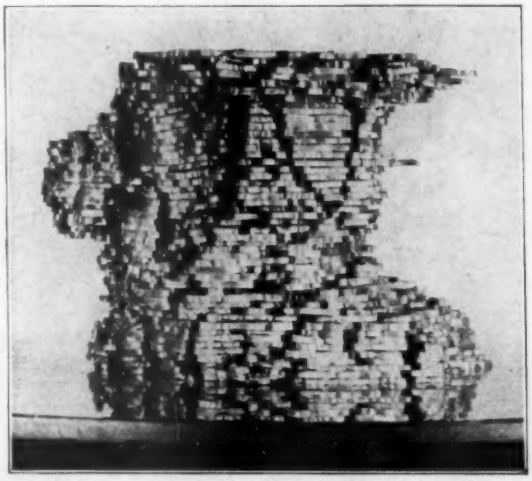

Fig. 30.—Profile view of untouched wax model of the thyroid from the case of exophthalmic goiter. The external contour of this model demonstrates the tendency of the parenchyma of the gland to branch into other regions by attenuation and spreading out of connective tissue septums. Wire struts support these offshoots or connecting bars of parenchyma; × 44.

nections with still further regions of parenchyma and so on ad infinitum as shown in the dissected specimen. Figure 27 illustrates the variations in shape and size encountered in the wax reproduction of the internal form of the follicles of the average section of the thyroid in exophthalmic goiter. This section was taken from the middle of the series and portrays the small group of follicles enclosed in the connective tissue envelope. When compared with figure 6, a similar photograph of the normal gland, it is at once evident that the average diameter of the follicles is much increased in the exophthalmic gland. The irregularities in contour due to infolding of the epithelium are also evident. Figure 28 is a top photograph of the model a little more than half completed.

The orientation lines on the glass base and scratched in the wax of the model may be seen as well as the fusing holes caused by piercing the wax models with the electrically heated needles. In the upper portion of the photograph may be seen the apexes of some follicles which have been completed at a lower level than the top plate of the model. These suggested a plateau, quite a distance below the top section of the model. The latter wax plate represents a section of the series a little more than half way through the middle of the model, and the outside edge or margin of this middle section corresponds with the position of the fibrous septums enclosing the follicles at that level in the gland and on the model. This also applies for each section. The shape of the model, therefore, exemplifies as a whole the form of the region of parenchyma enclosed by the septums. About the middle of the model

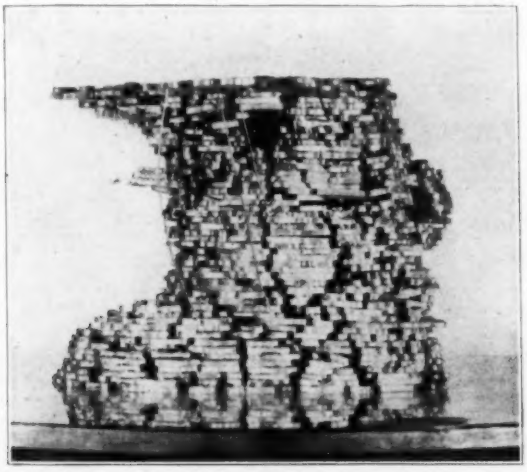

Fig. 31.—Another view of the profile view of the concluded but untouched model from the case of exophthalmic goiter. Note the spaces between the follicles and the stair-step appearance due to the piling of the plates; × 44.

the transverse area of follicles completely enclosed by the connective tissue bands is less in diameter than at any other level in the series. As will be noted in figures 28 to 31 inclusive, there is an irregular enlargement of the model at both the top and bottom. This is due to an increase in the number of follicles within the circumscribed area of connective tissue, or in other words to an enlargement of the space enclosed by these septums due to their separation or spreading apart. In figures 28 and 31 the lower plateau formation, in the upper portion of the photograph, is due to the increase in the size of the original group of follicles as the septums gradually fade out into the small strands of interfollicular connective tissue. At the top level in the lower portion of the photograph can be seen the tendency of one corner of the

model to spread out from the original shape. A top view of the finished model shown in figure 29 demonstrates this branching out, budding or spreading of the parenchyma very well. The profile views of the untouched model emphasize the tendency of the so-called "lobules" or original group of follicles to spread out and become joined with other regions as shown in figures 30 and 31. Wire struts were necessary to support these off-shoots of follicles. The narrowest region of the model is toward the middle, and it was here, in the stained sections, that the encircling fibrous connective tissue septums stood out most strikingly and completely surrounded the smallest group of follicles. Just as illustrated by the model, as one progresses from the

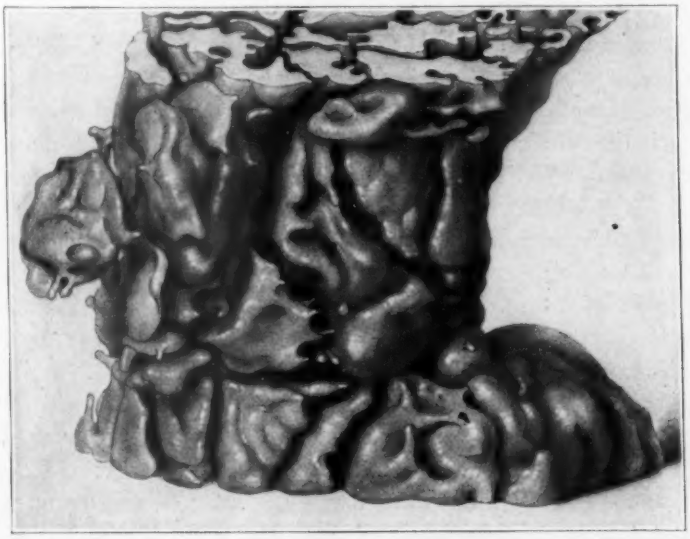

Fig. 32.—Drawing to scale of the finished model of the thyroid in exophthalmic goiter. Compare with figure 26, which is the completed model of the normal thyroid gland. The irregularity in shape and the much larger size of the individual follicles of exophthalmic goiter as compared with the normal are at once evident and the preponderance of small follicles in the normal thyroid is striking when compared with the almost total absence in the exophthalmic gland. Indentations of the wax model of the case of exophthalmic goiter are due to papillomatous infolding of the epithelium; × 75.

middle of the series toward either end, in looking at the stained sections, the fibrous septums become thinner, less pronounced and at the same time spread further apart. Concomitantly, they enclosed a greater number of follicles until there is such an attenuation and fading of the septums that they are reduced at certain points to small strands indistinguishable from the interfollicular connective tissue. It is at these points that there is a junction of the primary trunk of parenchyma

with other portions of the gland. The connecting bars are shown in the model as the projections of groups of follicles mentioned. From this it is evident that the apparent lobule of parenchyma of the thyroid completely surrounded and isolated by the bands or septums of connective tissue was an illusion, for if the model, and especially the stained serial sections are examined, it is at once evident that the connective tissue septums traverse the parenchyma of the gland in a very irregular manner and do not separate the thyroid into lobules. In the model of the thyroid tissue from a case of exophthalmic goiter, as in the case of the normal thyroid, there was no evidence of lobulation. Figure 32 is a drawing to scale of the finished model of the thyroid in exophthalmic goiter. The drawing was made at an angle that would permit a portion of the top of the model to be drawn, so that a transverse and longitudinal view of some follicles was obtained. The follicles have been smoothed off as in the model of the normal gland. It is again to be recalled that the wax casts shown correspond to the internal form of the follicle and the hollow indentations are due to the papillomatous infoldings of the epithelial lining into the lumen of the follicle. The follicles are on the average larger than those of the normal gland and their internal surface is relatively much more irregular. This irregularity is well shown in both the lateral and the top view. There are a few small follicles, but they are most conspicuous by their great diminution as compared with those of the normal thyroid (figs. 6 and 26). The magnification of both the normal and the exophthalmic models was 75 times. The internal shape of the follicles as seen in figure 32 varies a great deal but all are more or less spherical or spheroidal. Some are more flat and narrow, others rather shorter and of a greater diameter. Apparently the follicles in the center of the group are less flattened than those immediately adjacent to the connective tissue bands. There was no evidence of any outpouchings or pseudopodial-like protrusions of the follicles. They were all separate and distinct units completely disconnected. No tubular forms or coiled tubules were encountered in this model. There were no interacinar fetal cell rests or islands of epithelial cells disconnected or disassociated with the parenchyma of the thyroid. This point was again carefully checked in the series of sections 20 microns in thickness from which the wax model was made and also in another series cut from the same gland at a thickness of 10 microns.

COMMENT

Lalouette,[3] in 1750, first called attention to the minute structures of the thyroid gland by stating that the vesicles seemed to communicate

3. Lalouette, cited by Boechat: Recherches anatomiques sur la glande thyroide. Mémoires de mathématiques et de physique présentés a l'académie royale des sciences (savants étangers) **1**:159, 1873.

with each other. Later, in 1836, Jones [4] described the thyroid follicles in considerable detail as completely closed vesicles. Bardeleben,[5] in 1841, also concluded that the adult thyroid follicles were completely isolated structures. In spite of these two contributions, the majority of observers, such as Cruveilhier,[6] Virchow,[7] Boechat,[8] Zeiss,[9] and Hitzig,[10] followed Lalouette [3] in describing the follicles as forming a system of branched and communicating cavities within the gland. These opinions were all based on relatively inexact methods including observations on microscopic sections which were not cut in series. Such observations made on isolated sections of the gland were misleading and allowed of a great latitude of opinion which varied with personal interpretation. Streiff,[11] in 1897, was the first to employ an exact method when he adopted the technic of Born or the wax plate reconstruction method for the study of the normal human thyroid. He concluded that both isolated vesicles and branching forms occur in the normal thyroid although these vesicles do not form a system of communicating cavities throughout it. He found that the follicles were ovoidal or spindle-shaped, but that branched forms due to budding or secondary fusion were also encountered. Streiff [11] modeled only a few individual follicles separately, and did not investigate their relation to each other or to the gland as a whole. He used the inner epithelial margin of the follicle in tracing the outline of the vesicle on the wax so that his conclusions as to the shape of the follicle are based entirely on the internal and not on the external form. In 1923, Williamson and Pearce [12] conjectured that the thyroid organ consists of two lateral lobes joined by an isthmus. They stated:

> The lobes of the thyroid are composed of an aggregation of lobules lying in the meshes of the interstitial tissues of the organ. The parenchyma of the lobule

4. Jones, C. H., in Todd: Cyclopaedia of Anatomy and Physiology, vol. 4, pp. 1102-1118.

5. Bardeleben, S., cited by Zeiss: Observationes microscopicae de glandularum ductu excretorio carentium structura deque earundem functionibus experimenta, Diss. Inaug., Berlin, 1877.

6. Cruveilhier, J.: Glande thyroide, in Traite d'anatomie descriptive, ed. 2, Paris, vol. 3.

7. Virchow, R.: Die krankhaften Geschwülste, vol. 3, part 1.

8. Boechat, P. A.: Structure normale du corps thyroide, Thèse, Paris.

9. Zeiss, O.: Mikroskopische Untersuchungen über den Bau der Schilddrüse, Diss., Strassburg, 1877.

10. Hitzig, cited by Streiff: Beiträge zur Histologie und Histogenese der Struma, Diss., Zurich, 1897.

11. Streiff, J. J.: Ueber die Form der Schilddrüsen Follikel des Menschen, Arch. f. mikr. Anat., vol. 48, p. 579.

12. Williamson, G. S., and Pearce, I. H.: The Structure of the Thyroid Organ in Man, J. Path. & Bact. **26**:459, 1923.

is divided up by loose strands of fibro-elastic tissue into a series of well defined functional areas or gland units. The fibro-elastic tissue forms a capsule which completely circumscribes each gland unit and carries the intralobular blood and lymph vessels. . . . The loose fibro-elastic tissue capsule of each gland unit is lined by a pavement endothelium. The serous cavity so formed is directly continuous with the intra-lobular lymphatic channels. . . . The epithelium of the gland unit appears in the sinusoidal space as long cylindrical columns. Generally these twist and turn in various planes to accommodate themselves to the circumscribed area of the sinusoid. . . . Concisely stated, therefore, the functional gland unit of the thyroid organ is essentially a lymphatic sinusoid in which float columns of epithelium enmeshed by a highly specialized plexus of blood capillaries.

Williamson and Pearce,[12] by reverting to the inexact methods of the early observers before the time of Streiff,[11] fell into the same pitfalls and traps by drawing conclusions from the examination of occasional and not of serial sections. They assumed a lobulation of the gland which does not exist, and there is no evidence of any coiled cylindric columns in a lymphatic sinusoid in either the dissected or the reconstructed specimens. However, despite their errors, they deserve a great deal of credit for stirring up new interest in the subject, and their work exercised what may be termed an enzymatic action. Wilson,[13] in 1927, reported his observations on the thyroid follicle in man in the normal and pathologic conditions and successfully refuted the assertions of Williamson and Pearce.[12] He employed the reconstruction in wax previously originated by Streiff [11] in 1897. Wilson [13] corroborated Streiff's [11] observations for the normal thyroid follicle, but went further and modeled a few individual follicles from a hyperplastic and also from a colloid gland. Streiff [11] had selected the follicles he modeled from entirely different regions of the microscopic section. Wilson's [13] models contain a few more, from ten to twenty, follicles selected from a block of thyroid tissue from 0.3 to 0.6 mm. in dimensions. Although this number is slightly greater than was contained in Streiff's [11] reconstruction, it seemed to me preferable to include all the epithelial structures in a larger and more representative area of the gland by using a larger block of thyroid tissue. And further, it was decided to reconstruct all the follicles in that region in their exact relation to each other and not be satisfied to include so few as ten or twenty follicles from a given area. The study of only a certain number of follicles from an area, instead of all follicles or epithelial structures large and small occurring in that region, gives a less accurate impression of the variation in their size. Again, when the small follicles are eliminated in favor of the larger ones, one gets an entirely different impression of the composition of the parenchyma of that area. Wilson,[13] as well as Streiff,[11] made the drawing

13. Wilson, G. E.: The Thyroid Follicle in Man: Its Normal and Pathological Configuration, Anat. Rec. **37**:31 (Nov.) 1927.

for the model from the inside of the follicle, the free margin of the cells being used as a guide line. The former said: "This method has been followed, because it separates the follicles sufficiently to permit their entire extent to be seen, yet preserves their actual shape." But this, of course, revealed only the internal form of the follicle, which Streiff,[11] and later Wilson,[13] erroneously interpreted as the external shape. For this reason conclusions as to the budding, constriction, fusion or division of the follicles made first by Streiff [11] and later by Wilson [13] are incorrect, because they are based on the internal instead of the external shape of the follicle. As shown in this study by a comparison of the wax models, the internal form of the follicles, and the dissected specimens, or external forms of the follicles, differ widely in shape. Relatively few, if any, irregularities in the external contour of the follicles were observed. There was no evidence of budding, fusion, constriction or division of the follicle when seen and examined in its entirety. When only the casts of the inside of the follicle were studied, as in the wax reconstructions, many pronounced irregularities were seen, but such internal irregularities have no significance as to the activity of the unit or vesicle in the formation of new follicles. The only significance which can be attributed to the irregular internal shape is an increased proliferation and growth of the epithelium into the lumen of the follicle.

The great preponderance of small follicles in the wax model of the normal gland as well as in the dissected specimens, in proportion to large ones, is suggestive, at least, that the thyroid tissue is completely differentiated in the adult, and after puberty the number of follicles is probably not increased by the growth of secondary vesicles from primary follicles. The small follicles would seem to form a reserve supply of parenchyma which, when called on to function, does so by an increase in size due to hypertrophy and hyperplasia of the epithelium. This is further borne out by the lack of evidence of any new follicle formation, such as budding and division, in the smooth external contour of the dissected follicles and also the pronounced decrease in the proportion of small to large follicles in the exophthalmic gland. Wilson,[13] although having sectioned a small block not more than 0.3 and 0.6 mm. in thickness, said: "The dotted line in figure 4 represents the connective tissue septum enclosing the lobule," and went on further to discuss "the lobules." As shown by the reconstruction of a much larger (4 mm.) block, in this study, areas apparently completely surrounded by fibrous connective tissue septums, and thus forming a lobule, appear to exist only apparent for a few sections and are thereafter an illusion. In the reconstruction of the gland in exophthalmic goiter the fibrous septums were used as guide lines, and it was

demonstrated that the septums, in progressing through the gland, became separated, divided and attenuated and finally blended with the interfollicular fascia. In no instance in the wax reconstruction or the microdissections made was there the slightest suggestion of a lobulation of the gland. The group of follicles apparently surrounded by connective tissue always widened out and spread into other regions of parenchyma as a result of the irregular ramifications of the septums, so that the apparent circumscription of an area of parenchyma was always found to be an illusion. I am convinced, therefore, that the larger 4 mm. block of tissue cut serially in sections 20 microns in thickness reveals the error which may be made from conclusions based on evidence obtained from serial sections of too small a block cut 10 microns in thickness. A block of tissue of this size is not large enough to include a sufficient amount of gland to justify an opinion on the architecture of the thyroid as a whole.

It seems evident, then, that all of these investigations in the past have been concerned chiefly with the individual follicle and that in them the internal form of the vesicle has been considered the external form or true shape. As a result of this mistake conclusions as to the continued formation of new follicles in the adult, based on irregularities in the form or shape of the follicles reported in the past, are incorrect, because these irregularities occur only inside the follicle. The absence of these irregularities from the smooth, regular external form of the follicles, when dissected out in their entirety, would rather suggest that the probable growth of the gland occurring in the adult is due to the enlargement of follicles already formed rather than to the development of new or secondary ones.

Julius Casserius [14] was the first to describe the thyroid as a simple organ consisting of two parts. Bartholomaeus Eustachius [15] later described the organ as single, and gave to the structure joining the lateral lobes the name of isthmus. Since that time until the present there have been no reported studies on the structure of the entire gland and the character of the regions into which it is divided. As shown in this study, the lobes of the thyroid are irregularly broken up into regions or areas of tissue which are all joined together by connecting or annectent bars of parenchyma. In other words, the thyroid gland is divided, separated or honey-combed by an irregular system of communicating cavities which ramify all through it and until the gland is dissected these cavities are filled with tissue of mesenchymal origin and nerves.

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14. Casserius, Julius: De vocis auditusque organis historia anatomica, Ferraria, 1600-1601.

15. Eustachius, Bartholomaeus: Tabulae anatomicae, Romae, 1714.

The parenchyma of the thyroid consists of large areas in the shape of bands, plates, bars, stalks and bulbs which are joined together by connecting arms, annectent bars or slender twiglike processes of thyroid tissue. These areas, in turn, are composed of individual discontinuous spheroidal or ovoidal follicles which are held together in a network of fibrous connective tissue. Blood, lymph vessels and nerves ramify in this network of interfollicular supporting tissue. There is not the slightest suggestion of a true lobulation of the thyroid gland; there is only a mass of thyroid tissue which has been irregularly broken up by a complex system of cavities later filled with mesenchymal tissue. An embryologic basis for this rather unusual manner in which the thyroid is subdivided has been shown by Norris [16] in his study of the human embryo. After complete separation of the thyroid from the pharynx the gland grows rapidly and forms a bilobed platelike mass, thick and irregular, ventral to the trachea and in a plane parallel to the long axis of the body. At this stage, in 7 mm. embryos, the primordium is usually from about five to six cells thick in cross-section, and, according to Norris,[16] there appear in this gland mass a number of completely closed cavities, at first tiny clefts, which suggest that the cells about them had pulled apart and they had apparently resulted from cracks or splitting of the tissue. These cavities increase in size and are brought more closely together. They vary markedly in shape, size and general position in the same and in different fetal thyroids. They have no visible content, but possess a distinct sharp outline. As growth continues these cavities become confluent, and finally as they open to the outside they are invaded by the adjacent vascular mesenchyme. The gland mass which was at first a solid body in the embryo is transformed into one that is hollow and the cavities of which are surrounded by epithelial plates. As a result of this process the gland comes to be made up of smooth epithelial platelike regions of parenchyma which unite freely with each other and ultimately come to form an extremely complex structure. Later, additional plates are formed by a process of budding and growth from plates created primarily in the initial breaking up of the gland mass. This transformation has occurred in the prefollicular stage. The morphogenesis of the thyroid follicles of the chick has been reported (1929) by W. Bradway,[17] who corroborated the observation on the human embryo made by Norris [16] in stating:

> By growth of cells and differentiation, the original impaired anlage becomes two solid bodies which, at the end of six days, contain nonfollicular spaces into which the mesoderm enters. At the end of eight days each glandular body has become a fenestrated labyrinth of parenchyma two cells thick.

16. Norris, Edgar H.: Am. J. Anat. **4**:443, 1918.

17. Bradway, Winnefred: Abstract no. 2216, Wistar Institute Bibliographic Service, no. 114, Feb. 28, 1929, to appear in Anat. Rec.

From this study it would seem that the irregular subdivision present in the human embryo persists into adult life. It was found that the greatest variations in shape and size occurred not only in the subdivision of the same gland but also in that of different ones.

It is interesting to note how, when once entrenched in the text-books, a statement is handed on for a long time unchallenged. In 1883, Wolfler [18] described rests of fetal cells between the follicles which he thought persisted into adult life and later gave rise to tumors or neoplasms of the thyroid gland. These have been referred to as interacinar, intervesicular as well as interfollicular cell rests. Wolfler examined only isolated sections, rather thick and poorly stained, for the technic of cutting sections in series was not known at that time. It is, therefore, quite comprehensible that Wolfler's methods were inexact and his conclusions inaccurate. In the present study after a most meticulous examination has been made of two series of sections, one cut 10 and the other 20 microns in thickness from both the normal thyroid and the gland taken from a case of exophthalmic goiter, not the slightest evidence of cell rests, either fetal or adult, between the follicles could be found. Only completely differentiated epithelium was encountered in the thyroid, and further, the only epithelium found was associated with some follicle presenting the normal appearance and arrangement of the adult thyroid parenchyma. The only possible explanation of a manner in which such a misinterpretation as Wolfler's could have occurred and also for the persistence of the same mistake as shown by many, even recent, articles is that a tangential section through the dome of an underlying follicle sometimes gives the impression of a group of disconnected epithelial cells. As a matter of fact, if the section is one of a series, it can be proved that the disconnection of the epithelium is only apparent and that the next section shows them associated in the formation of a follicle. It is believed, then, that this study justifies the conclusion that there are no such epithelial or fetal cell rests in the thyroid gland, whether it is normal or whether it comes from a case of exophthalmic goiter, and that the persistence of any type of fetal tissue in the adult thyroid does not occur.

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18. Wolfler, A.: Ueber die Entwicklung und den Bau des Kropfes, Arch. f. klin. Chir., 1883, vol. 29.

THE GALLBLADDER

ITS FUNCTIONS AND SOME OF THEIR DISTURBANCES IN THE LIGHT OF RECENT INVESTIGATIONS *

BÉLA HALPERT, M.D.
CHICAGO

The purpose and functions of the biliary vesicle are still debated problems (Mann,[1] Haberland,[2] Rost,[3] Lütkens,[4] Chiray and Pavel,[5] Pfuhl,[6] Westphal and Schöndube,[7] Boyden,[8] Blond,[9] Babkin,[10] Körte,[11] Moynihan,[12] Lyon,[13] Whitaker,[14] Rolleston and McNee[15]). The view most widely accepted regards the gallbladder as a reservoir the function of which is to supply concentrated bile whenever there is call for such in the intestine. This traditional concept, however, as may easily be gathered from the literature, does not provide the best explanation for such phenomena as the formation of biliary concretions and hydrops of the gallbladder, nor does it account for the occasional absence of clinical signs or symptoms in the presence of gallstones, and the not infrequent occurrence of typical signs and symptoms of cholelithiasis in the absence of concretions.

The appreciation of this fact, i. e., that the current notions of the function and dysfunctions of the biliary vesicle were difficult to harmonize with a number of well established clinical observations, was perhaps the principal reason that induced the German Surgical Society in 1923 to have a symposium on the gallbladder at their yearly congress in Berlin. John Berg, the Nestor of the Scandinavian surgeons, author [16] of a new theory of the function of the gallbladder, was to deliver the opening address. This appeared in the transactions of the society,[17] but was not presented because of the author's illness. Aschoff, who took his place, summarized the state of knowledge of the subject.[18] His address is included in the volume of lectures which he delivered in this country in 1924.[19] On listening to this address, one was struck by the emphasis that he laid on the resorptive powers of the gallbladder mucosa. His statements were based not so much on work in his own laboratory as on the experimental results of Rous and McMaster of the Rockefeller Institute.[20] The work of these authors marks the commencement of a new epoch leading to the present better understanding of some of the

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* From the Department of Pathology and the Otho S. A. Sprague Memorial Institute, University of Chicago.

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principles underlying the functions and dysfunctions of the biliary vesicle. When their experimental results were evaluated, it became clear at once that disturbance of the resorptive function of the gallbladder was the factor leading to stagnation of bile in the viscus, and not obstacles of a mechanical nature hindering free in and outflow—that is, the exchange of bile in the biliary vesicle—as was formerly advanced by Aschoff and Bacmeister.[21] Thus, the concept of one of the generally accepted fundamental causes of the formation of gallstones—biliary stasis in the gallbladder—suffered a rather radical change.

Much impressed by the bright light thrown on the subject by this sudden discovery, I reconsidered the morphologic data and some of the experimental and clinical observations that I had collected from 1921 to 1923. This resulted in my becoming thoroughly convinced that the old conception of the function of the gallbladder was inadequate to explain its dysfunctions, and I began to question seriously whether the bile which once entered the gallbladder ever left it again through the cystic duct. Believing that, after three years' study of the biliary system, I had sufficient data to justify a new suggestion concerning the function of the gallbladder, I presented the idea in February, 1924, before the Society of German Physicians in Prague.[22]

Sweet in Philadelphia delivered a Mütter-Lecture in December, 1923, entitled "The Gallbladder; Its Past, Present and Future."[23] In this lecture, which was published six months later, Sweet advanced much the same idea as mine, i. e., that the bile which once has entered the gallbladder does not under ordinary conditions leave it again through the cystic duct, but is resorbed by the mucous membrane of the biliary vesicle, and the constituents then returned by the way of the veins and lymphatics into the liver and the general circulation, respectively. While both of us agreed that the bile entered the gallbladder not to be stored there and in time expelled but to be resorbed in toto by the gallbladder mucosa, our interpretations as to the service rendered by the gallbladder through this function were somewhat different. According to Sweet's conception, the main function of the gallbladder was to play a part in the cholesterol metabolism. It is of interest to recall in this connection that Virchow[24] was the first, in 1846, to notice the presence of lipoidal substances in cells of the gallbladder mucosa. He regarded these cells later (1857) as being concerned in the intermediate metabolism of fats, considering a part of the fat of the bile to be resorbed by the gallbladder mucosa. Thus, Virchow concluded about seventy years ago that "the gallbladder is not a mere reservoir but has a further function, for through it fats find an intermediate passageway back into the circulation."

My conception was that the gallbladder performs at least two main functions: first, the return of important constituents of the bile into the circulation, and second, by the resorption of bile, the relief and

regulation of the pressure within the biliary system while the sphincter of the ductus choledochus is closed.

This was, then, the state of affairs about the beginning of 1924, when cholecystography was still in the hands of the discoverers and, indeed, in an early experimental stage. Cholecystography, the ingenious invention of Graham and Cole [25] for rendering the gallbladder content opaque to the roentgen rays, opened a new field for the study of the function of this organ and quickly became a most valuable addition to the list of indispensable methods of clinical diagnosis. It would lead, however, too far afield to review, and perhaps it would be too early to evaluate, the wealth of accomplishment since cholecystography became a routine clinical procedure.[26] Nevertheless, it may be said that in spite of the refined technic in producing shadows and estimating the amount of the content of the gallbladder,[27] most of the problems in regard to the function of this organ are still under active discussion. One investigator, Blond [28] of Vienna, recently emphasized the fact that interpretations of the results of cholecystography are easier and the manifestations less contradictory if it is assumed that the bile enters the gallbladder not to be stored there and in time expelled, but to be resorbed in toto by the gallbladder mucosa. With this I agree. The fact that bile may and does leave the gallbladder occasionally in small quantities does not invalidate this conception. Nor do the experimental results of Boyden,[29] Whitaker,[30] Higgins and Mann,[31] Hamrick,[32] Ivy and Oldberg [33] and others make it untenable. It has been shown by these authors that the gallbladder can be made to expel some of its content, and they have demonstrated the actual passage of certain opaque substances from the biliary vesicle into the duodenum. This, however, is far from proving that the gallbladder empties most of its content through the cystic duct under ordinary conditions or that its function is to do so. In an evaluation of experimental results of this kind, the possible anatomic variations of the neck of the gallbladder, of the cystic duct, and in man, also, particularly of the folds of Heister,[34] must be taken into account.[35] These structures, as will be shown later, are the ones entrusted with the control of the passage of bile toward the gallbladder. Their arrangement is such as to indicate that their function is to regulate the inflow and to hinder or prevent the outflow.

MECHANISM OF GALLBLADDER

The mechanism of the flow of bile into the gallbladder may perhaps be considered first. Coming from the hepatic ducts into the ductus choledochus, the bile may, of course, flow via the cystic duct into the gallbladder or through the opening of the papilla of Vater into the duodenum.[36] It is known that the outlet into the duodenum is only periodically open, whereas the passage toward the gallbladder is always

open. However, the bile has to make its way through a twisted tube which has a system of spiral-like folds narrowing its lumen. What is the force that drives the bile through the narrow cystic duct into the gallbladder in spite of the alternately arranged protruding folds of Heister?

Through a hole in the gallbladder wall caused by a needle-prick, bile escapes abundantly, indicating pressure within. As soon as the cystic duct is ligated, the flow decreases, showing that the pressure is more likely due to hydrostatic pressure within the bile ducts than to tension of the gallbladder wall, the contraction of which would tend to close the opening and stop the flow. In a pipet connected with the cannulated ductus choledochus of an anesthetized rabbit, the bile column may be observed to move forward only during inspiration. From this, it appears as if the pressure exerted on the liver during inspiration might be the force driving the bile into the gallbladder. When the entrance into the duodenum is closed, the bile ducts and the gallbladder form a Y-shaped communicating vessel of which the ductus choledochus is the stem, the common hepatic duct the one branch, and the cystic duct the other (fig. 1). The roots of the hepatic ducts being filled with bile high up to the smallest intrahepatic bile ducts, the fluid when pressed on will escape through the cystic duct into the gallbladder. It seems, then, as if the muscular coat of the gallbladder, the curves of its neck and the narrow cystic duct with the complicated folds of Heister were arrangements that compensate for pressure changes in the hepatic ducts.

It is in accordance with this that bile or any other fluid, injected with a slight pressure into one of the bile ducts, at any place above the duodenal portion of the ductus choledochus, first fills up the hepatic ducts and the ductus choledochus and then the cystic duct and the gallbladder. Before the gallbladder becomes much distended, the fluid enters the duodenum. But if there is a hole in one of the bile ducts, the injection of the gallbladder from the ducts does not succeed: the fluid passes through the hole, and neither the gallbladder nor the duodenum receives any. This is true for man or for animals tested, alive or dead.

From these experiments, simple as they are, it is safe to conclude that when the duodenal end of the ductus choledochus is closed, pressure, perhaps that exerted on the liver during inspiration, forces the bile into the gallbladder. The anatomic arrangement of the cystic duct with its heisterian folds and the curves of the neck of the gallbladder regulate the inflow of bile, whereas the muscular coat of the gallbladder prevents overdistention and produces adjustment in size at all times to the varying content. The latter statement, i. e., that the chief function of the muscular coat of the gallbladder is to prevent overdistention and to produce adjustment in size to the varying content and not, as is generally held, the emptying of the viscus, needs further elaboration.

If fluid is injected into the gallbladder with a syringe, the viscus first stretches to its maximum capacity, and while the resistance of the heisterian folds is successively overcome, one by one, the fluid passes through the cystic duct. Any surgeon or pathologist of experience can tell how difficult it frequently is to squeeze bile out of the normal gallbladder. If at necropsy the biliary vesicle is removed and freed of its

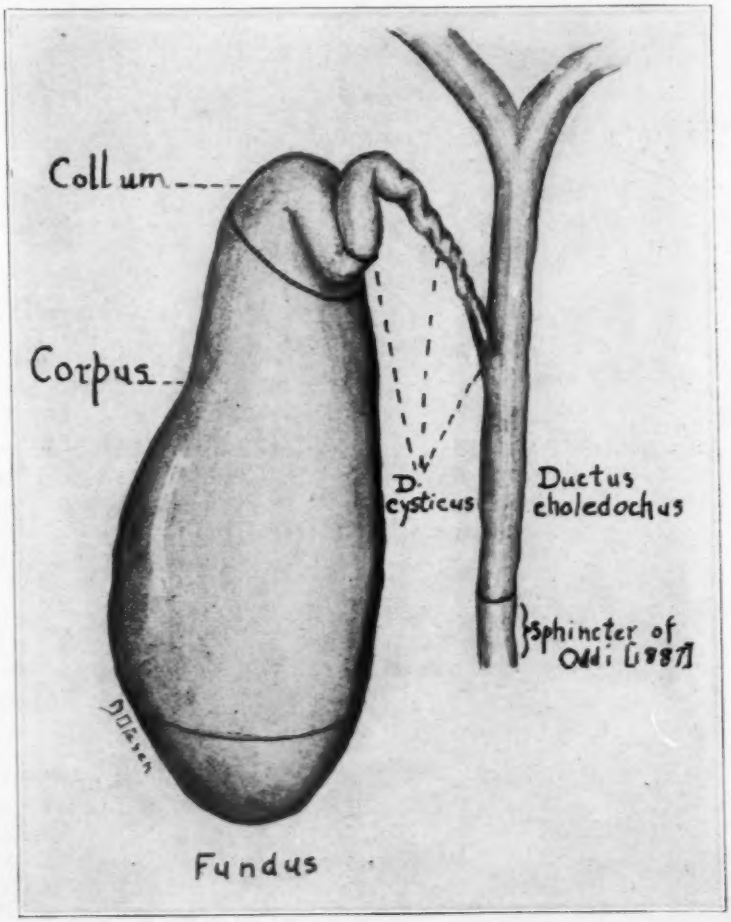

Fig. 1.—Diagram of the extrahepatic bile ducts and the gallbladder. They form a Y-shaped communicating vessel of which the ductus choledochus is the stem, the common hepatic duct the one branch and the cystic duct the other.

content by cutting open the fundus, the heisterian folds usually prove "competent to the water test." The first fold of Heister, which marks the commencement of the neck of the gallbladder, is usually a high (about 7 mm.), thin, semilunar membrane which narrows the lumen to less than a third of the original diameter (fig. 2). The orifice is

eccentrically situated and leads into the upper limb of the S-shaped turn of the neck. At the lower limb of the S-shaped turn, a second fold narrows the lumen. Here the neck continues into the cystic duct, which tapers gradually toward its junction with the common hepatic duct (fig. 3). The crescent-like folds protruding into the lumen of the cystic duct are apparently arranged in a fashion to act as a system of "one way valves": they permit the inflow but prevent or hinder the outflow of bile from the gallbladder. The topographic relations and the structure of the gallbladder lend further support to this idea: the longitudinal axis of the gallbladder runs nearly parallel to the vertebral column; the tip of the fundus is lowermost and lies usually on a lower

Fig. 2.—The first fold of Heister. The commencement of the neck of the gallbladder is marked by the first fold of Heister, which is a thin semilunar membrane narrowing the lumen to less than a third of its original diameter. The orifice is eccentrically situated (drawing of a specimen of Dr. Sweet).

Fig. 3.—Heister's illustrations of the neck of the gallbladder and the cystic duct. They show that Heister's conception of the anatomy of these structures was clear.

level than the papilla of Vater; furthermore, half of the surface of the body of the gallbladder is attached to the liver. Under these conditions the muscular coat would have to empty the gallbladder against the hydrostatic pressure of its own content, as well as force the bile through a small opening against the resistance offered by the curves and folds of the neck and the cystic duct.

The actual strength and arrangement of the muscular coat of the gallbladder, the history of its development and its behavior when it hypertrophies under stress are all in favor of the assumption that emptying of the viscus is not the function of the muscular coat. Genetically, the muscular coat of the gallbladder is probably a muscularis mucosae.

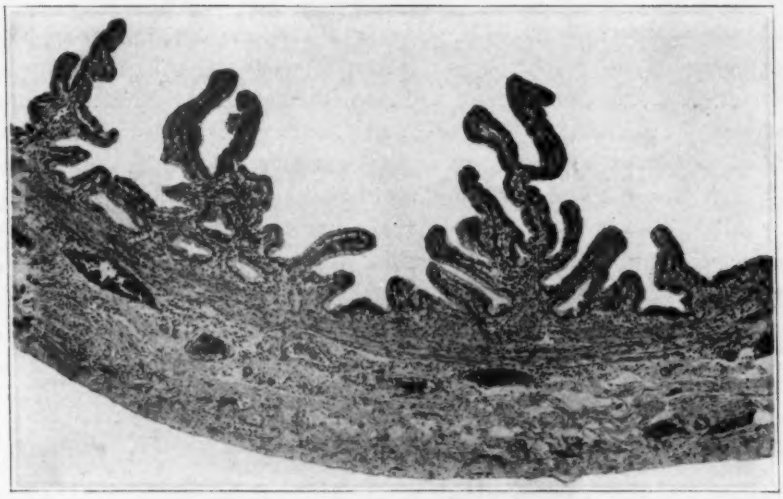

Fig. 4.—Cross-section from about the middle of a normal gallbladder of a 33 year old woman; × 40. It illustrates the closeness of the muscularis to the lining epithelium, the absence of a submucosa, the richness of the mucosa in folds and the absence of glands.

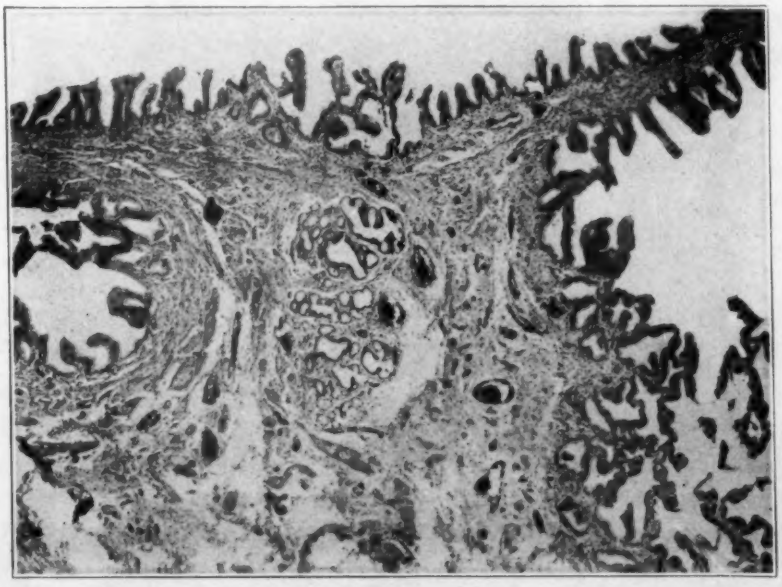

Fig. 5.—Glands in the neck of the gallbladder of a 24 year old woman; × 30. In this cross-section, glands of an alveolar or tubulo-alveolar structure appear beneath the muscular coat, just as Brunner's glands, which penetrate the muscularis mucosae and lie in the submucosa.

In favor of this view are: the absence of a submucosa, the closeness of the muscularis to the lining epithelium (fig. 4), its comparatively late appearance in the development and also the fact that some of the glands occurring in the neck of the gallbladder penetrate the muscularis just as Brunner's glands perforate the muscularis mucosae of the duodenum [37] (fig. 5). The thickness of the muscularis varies considerably in different gallbladders and also in different parts of the same gallbladder. Usually there is a gradual but definite decrease toward the fundus and a slight increase toward the neck (figs. 6 and 7). Approaching the first

Fig. 6.—Longitudinal section of the distal half of the gallbladder of a female infant 38 days old; × 5. The muscular coat is thinner about the fundus than in the middle portion.

heisterian fold the muscular coat becomes thinner, and the arrangement into inner, rather longitudinal and outer circular or oblique bundles seems to become disorganized. The bands of muscle fibers about the base of the heisterian folds and curves of the neck were interpreted by Lütkens [4] as a "collum-cysticus sphincter," which of course does not exist.

It should be added to all this that in some animals a contraction capable of bringing the mucosa of opposite sides into contact with one another is altogether impossible because of the structure or the topography of the gallbladder. In the two-toed sloth (*Choloepus hoff-*

manni [38]), for example, on that side of the gallbladder which is attached to the liver the muscularis is missing in some places and scant in others as compared with the relatively large amount of musculature on the peritoneal side, which, however, comprises only one third of the circumference of the viscus (fig. 8). In most *rhesus* monkeys about two thirds of the entire surface of the gallbladder is embedded in the liver (figs. 9 to 11).

The cat's gallbladder is often of a peculiar shape, having two or more fundi, some of which may be lodged deep in the substance of the liver. In Boyden's [39] series of more than 2,500 cats, one in eight

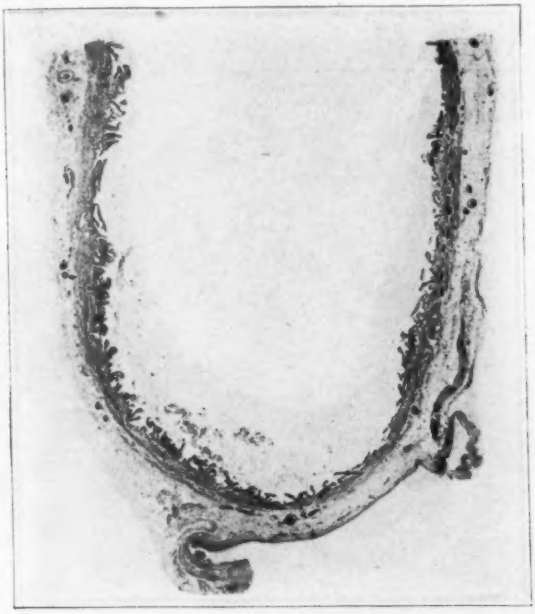

Fig. 7.—Longitudinal section of the fundus of the gallbladder of a 57 year old woman; × 5. The muscular coat is hypertrophied and is thinnest about the dome of the fundus. The mucosa is seen to dip down between the muscle bundles forming deep outpouchings toward the external layers of the gallbladder: "Rokitansky-Aschoff sinuses" (see fig. 17). This gallbladder contained a number of "mixed gallstones." The size and shape of the viscus was about normal; the wall, however, appeared thickened. Microscopically, a cellular infiltration was noted in the subepithelial layer, in the intermuscular septums and to a lesser degree, also, in the perimuscular layer. The muscularis, which is hypertrophied, appears somewhat edematous. A slight edema is noted also in the rest of the layers, especially in the perimuscularis.

possessed some form of accessory gallbladder (fig. 12). Each of two lions that I had an opportunity of examining had bilobed gallbladders.[37] In the dog the lobes of the liver surrounding the free surface of the

gallbladder, are modeled to the shape of the viscus. Instances are known in which the gallbladder is totally embedded in the liver; in these cases, of course, an emptying contraction of the viscus is, *a priori*, utterly impossible. I have two specimens of this kind, one from a *rhesus* monkey (fig. 13) and one from a pig (fig. 14). The fact that these gallbladders could not empty their content through the cystic duct apparently did not interfere with their normal function; both contained no concretions or showed any demonstrable pathologic change.

Data thus far obtained by studying the spontaneous contractions of the isolated gallbladder of the dog also indicate that the function of the muscular coat is that of preventing overdistention and of effecting adjustment in size to the varying content. Experiments performed

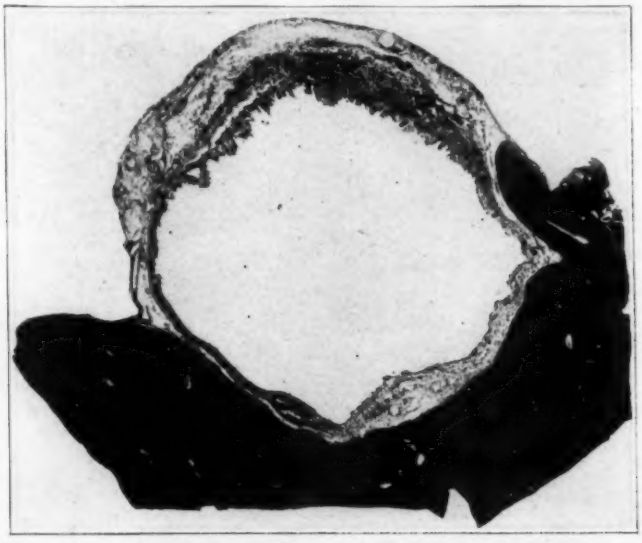

Fig. 8.—Cross-section through the gallbladder of a two-toed sloth (Choloepus hoffmanni); × 5. The wall of the gallbladder is thinner and the muscle bundles scant or absent where the organ is attached to the liver. On the opposite side there is a rather thick layer of muscle bundles, but only to an extent of about one third of the circumference of the viscus.

together with Dr. Julian H. Lewis [40] were carried out in the following manner: The content of the freshly removed gallbladder was replaced with Locke's solution after thorough rinsing of the mucosa. The organ was then placed in an oxygenated bath of Locke's solution at body temperature. A specially constructed glass cannula tied into the neck of the gallbladder permitted accurate estimation of the fluid introduced into the viscus and, by its connection with a writing tambour, the registration of any change in the inner volume. Rhythmic contractions usually commenced soon after proper adjustments were made. They

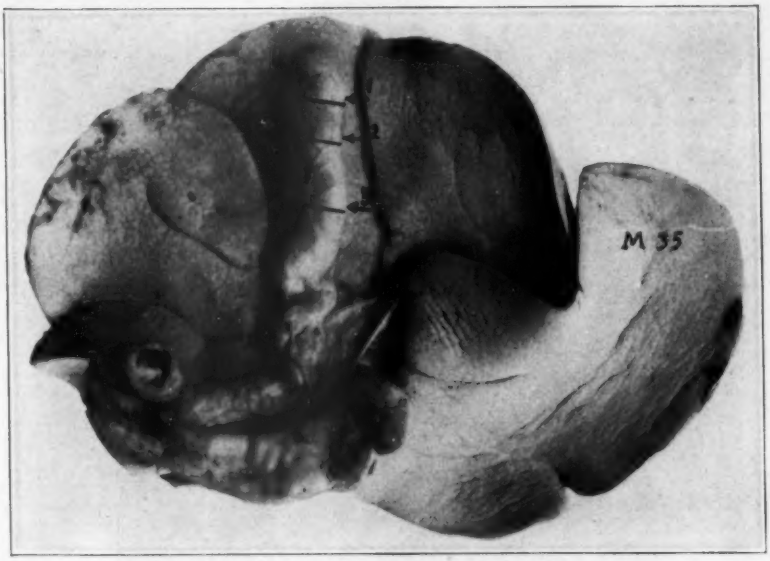

Figure 9

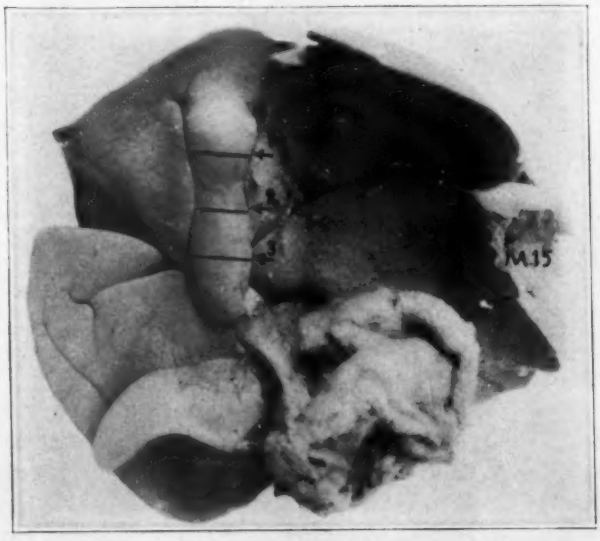

Figure 10

Figs. 9 and 10.—Topography of the gallbladder in the rhesus monkey (Macacus rhesus). The tip of the fundus of the gallbladder does not reach the inferior margin of the liver but is embedded in the liver. The border of the fossa vesicae thins out gradually so that the gallbladder is framed in the liver like a gem set in a ring.

were usually from 2 to 46 mm. high, equivalent to the displacement of from 0.1 to 2.3 cc. of Locke's solution, and appeared at a rate of about 1 to 3 per minute. It was found that when the fluid content of the viscus was raised or lowered a change was registered, but soon adjustment occurred and the curve returned to the previous level and resumed its former shape (fig. 15).

It is known that the muscular coat of the gallbladder hypertrophies under stress. On such gallbladders dilatation of the cystic duct, exaggeration of the curves of the neck and the "relative insufficiency" of the heisterian folds are constant and conspicuous (fig. 16), but it is the

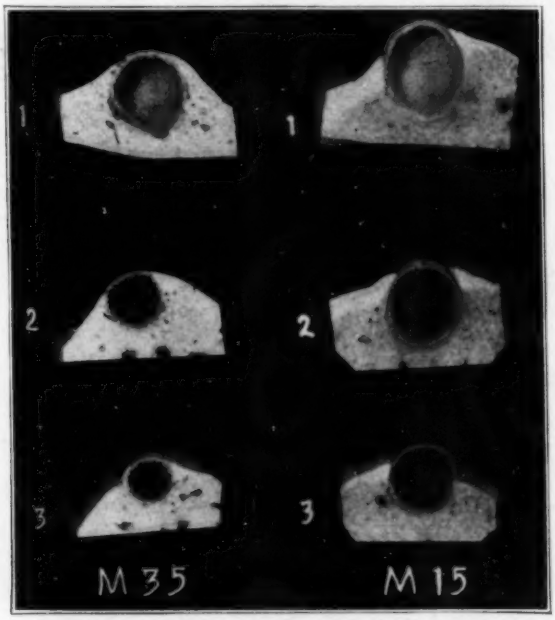

Fig. 11.—Transverse sections of the same gallbladders at levels marked are shown, illustrating that from two thirds to four fifths of the entire surface of the gallbladder is embedded in the liver.

presence of numerous hernia-like outpouchings of the gallbladder mucosa, the "Rokitansky-Aschoff sinuses," [41] which really tell the story. These outpouchings of the mucosa penetrate the muscular coat and appear with their dilated fundi in the perimuscular layer (figs. 17 and 18). It is evident that extreme contractions following prolonged and repeated overdistentions of the viscus lead to their formation: overdistention because it increases the size and possibly also the number of potential holes in the web of the muscularis, and extreme contractions, because as the viscus diminishes in size and the mucosa adapts itself to a smaller area of attachment the mucosa may be forced in some places

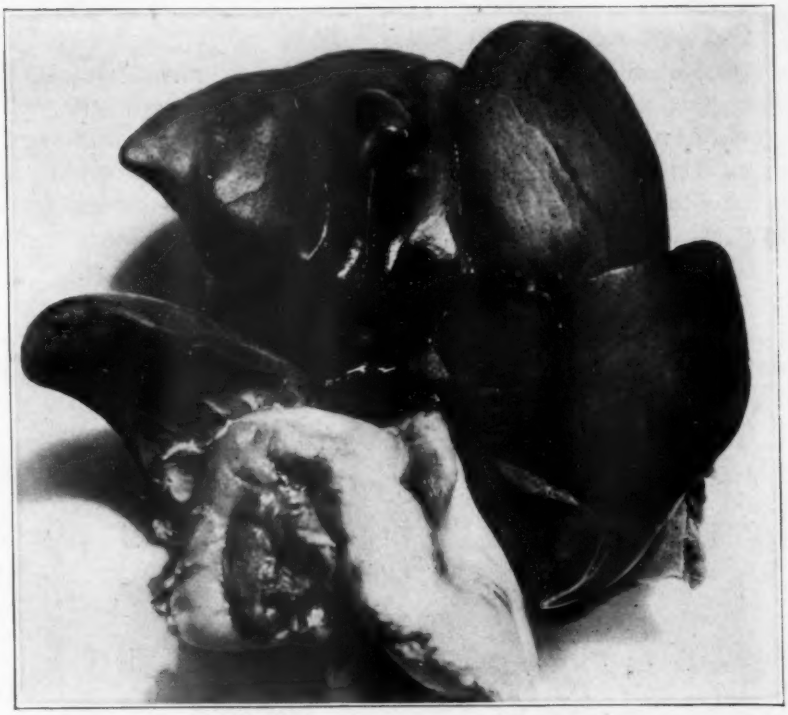

Fig. 12.—Trilobed gallbladder of a rhesus monkey.

Fig. 13.—Gallbladder of a rhesus monkey, embedded in the liver.

to dip down between the muscle bundles and protrude toward the external layers.[42] Evidently, then, the process which calls for a hypertrophy of the muscular coat of the gallbladder leads also to the formation of hernia-like outpouchings of the mucosa which because they penetrate the muscular coat, certainly do not favor an effective contraction which would completely obliterate the lumen of the viscus (fig. 7).

EXPERIMENTS

An incidental observation made in Dr. Petroff's laboratory in the Trudeau Sanatorium gave new impetus to the search for conclusive evidence for or against the new hypothesis of the function of the gall-

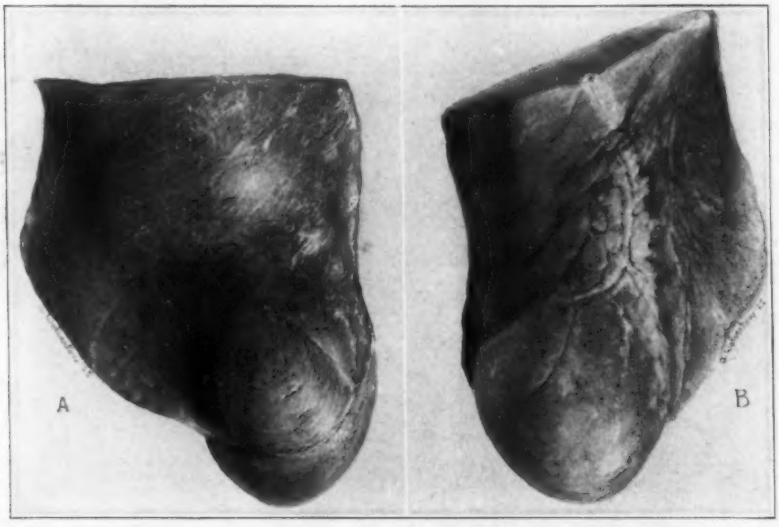

Fig. 14.—Gallbladder of a pig, embedded in the liver. *A* is an anterior, *B* a posterior, view.

bladder. Dr. Petroff treated his colony of *rhesus* monkeys, affected with intestinal parasites, orally with methylene blue (methylthionine chloride, U. S. P.). At necropsy of one of these monkeys several days after the last dose, methylene blue was discovered in the gallbladder. Thus methylene blue seemed a promising agent for determining the correctness of the hypothesis that the bile which once has entered the gallbladder does not, under ordinary conditions, leave it again through the cystic duct. Experiments were carried out on rabbits after a method had been found for the quantitative determination of methylene blue and its leukoform in bile.[43] In one series the methylene blue was given intravenously and in another by stomach tube, in doses of 20 mg. per kilogram of body weight, that is, 2 cc. of a 1 per cent solution.

It was found that in the rabbit anesthetized with ether the methylene blue appeared in the bile collected from the cannulated ductus choledochus within a few minutes after intravenous injection of the dye and reached highest concentration within less than one hour. This concentration of from 1 : 1,100 to 1 : 3,300 was approximately maintained for an hour or two. Then, dropping gradually, it showed from a fifth to a fifteenth of the highest concentration by the end of the sixth hour, the values ranging between 1 : 9,000 and 1 : 36,000. The bile removed from the gallbladder at the same time, i. e., six hours after the injection,

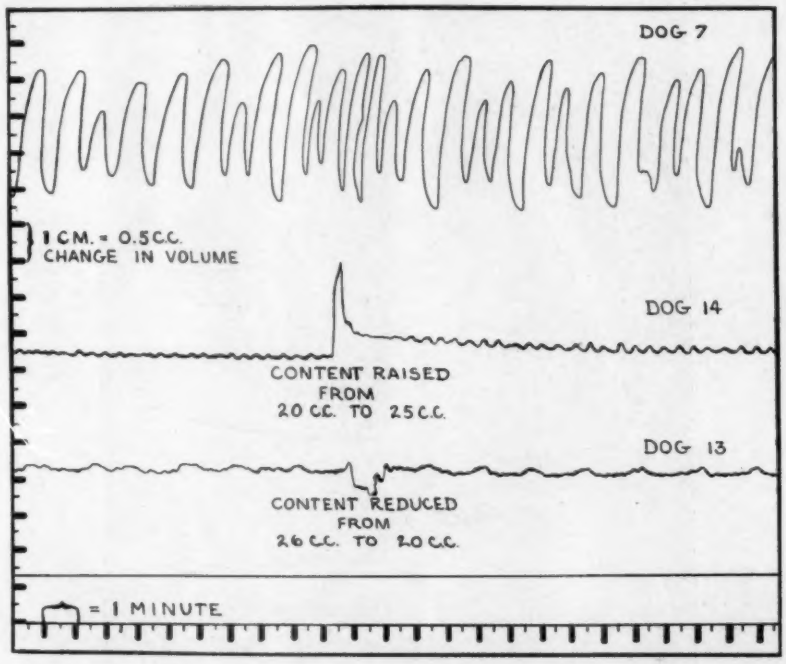

Fig. 15.—Spontaneous contractions of the isolated gallbladder of the dog (Halpert-Lewis). The upper curve (dog 7) shows spontaneous rhythmic contractions as high as 46 mm., equivalent to the displacement of about 2.3 cc. of Locke's solution. The middle curve (dog 14) shows the effect of raising the fluid content from 20 to 25 cc. The lower curve (dog 13) shows the effect of reducing the fluid content from 26 to 20 cc. The middle and the lower curves illustrate that when the fluid content of the gallbladder is raised or lowered a change is registered, but soon adjustment occurs and the curve returns to the previous level and resumes its former shape.

usually contained from two to twenty-two times as much methylene blue as that contained in the last specimen of bile obtained from the ductus choledochus. Not only that, but at times, the concentration of methylene blue in the bile removed from the gallbladder was much higher—1 : 720

and 1 : 800—than the highest concentration ever reached in the bile collected from the ductus choledochus. This observation was the more remarkable since the gallbladder was never empty to begin with and since during the entire period of the experiment bile was passing freely through the cannulated ductus choledochus at a rate of from 5.5 to 13 cc. per hour.

In explaining these observations, it was necessary to assume either that bile had passed through the cystic duct into the gallbladder irrespective of the cannula in the ductus choledochus and that in the biliary

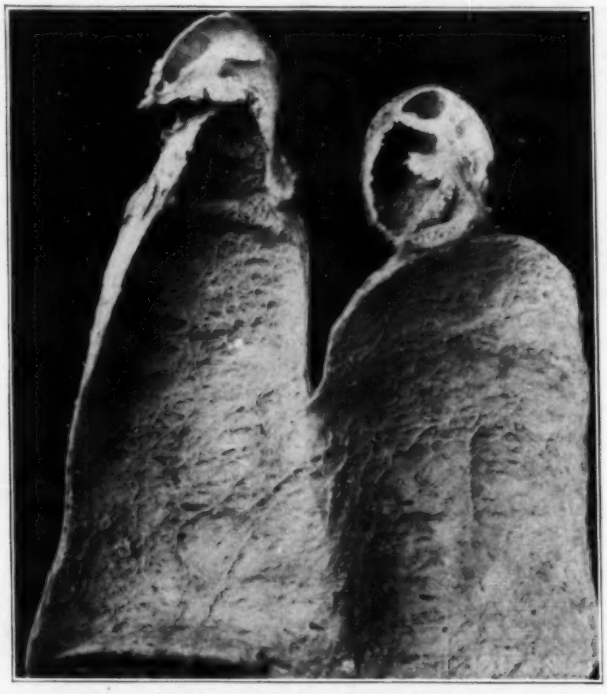

Fig. 16.—The neck of a hydropic gallbladder of a 35 year old woman. The neck and the cystic duct are divided by a longitudinal section. The curves of the neck are exaggerated and the cystic duct is dilated to about ten times its original diameter. The gallbladder measured about 20 cm. in the longitudinal and 7 in the transverse diameter. It was filled with a viscid opaque fluid (white bile) and contained several "mixed gallstones," some of which were facetted.

vesicle a rapid concentration of the dye had taken place, or that the main bulk of the methylene blue reached the gallbladder by way of the blood stream and was excreted by its mucous membrane. Mann's experiments with rose bengal supported the latter assumption.[44] In order to clear the situation, in two rabbits the cystic duct was ligated, with particular care not to interfere with the circulation, the usual

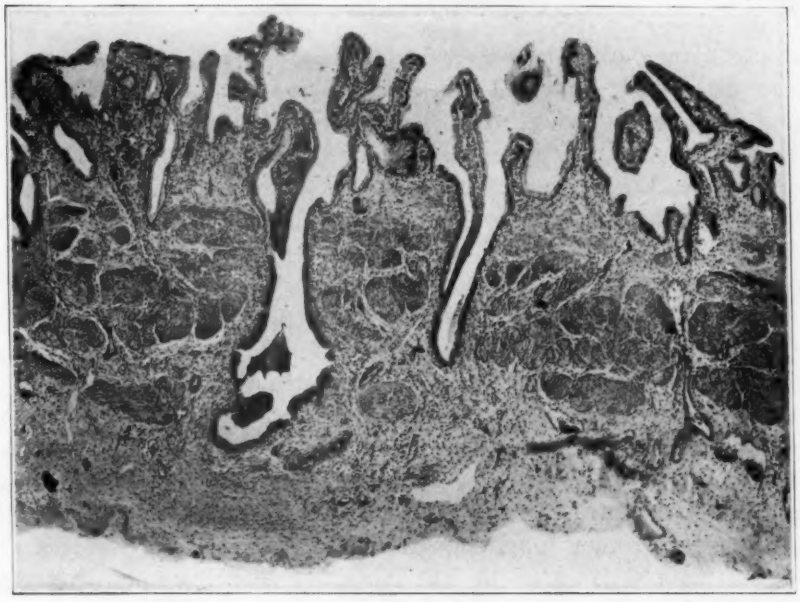

Fig. 17.—Rokitansky-Aschoff sinuses in a longitudinal section taken from about the middle of the gallbladder of a 57 year old woman; × 24. The fundus of one of the two outpouchings is situated in the perimuscular layer and is wider than the part connecting it with the lumen of the gallbladder (section of the same gallbladder as fig. 7).

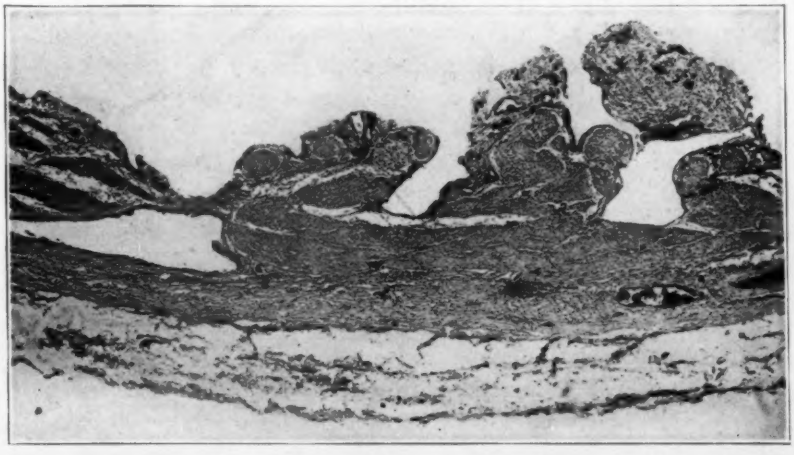

Fig. 18.—Rokitansky-Aschoff sinuses in a transverse section of a hydropic gallbladder of a 50 year old man; × 32. The lining epithelium is flattened. Outpouchings of the mucosa bulge into the muscularis, one appearing in the perimuscularis. The muscular coat is hypertrophied—the arrangement of the muscle bundles into inner longitudinal and outer rather oblique or circular bundles is distinct. This gallbladder was filled with "white bile" and contained numerous "mixed gallstones" of various shapes and sizes.

amount of methylene blue injected intravenously and the bile removed from the gallbladder two hours later. The estimated content of the biliary vesicle was about 2 or 3 cc. at the time of the ligation and injection. About two hours later less than 0.2 cc. of bile could be obtained from the gallbladder, which contained a hardly determinable trace of methylene blue. Obviously, then, the gallbladder mucosa was not excreting the dye. In other words, the methylene blue found in the gallbladder must have entered the viscus via the cystic duct.

In another series of experiments, the methylene blue was given by stomach tube in exactly the same amounts as in the experiments with injections. After the administration of the dye the animals remained in their usual environment and on their usual diet until the time of operation, particular care being taken that there was always food in their cages. The operation was performed at certain stipulated intervals between the twelfth and seventy-second hour after the ingestion of the dye in order to allow time enough for the action of any physiologic process which would tend to free the gallbladder from its methylene blue content.

It was found that bile collected from the cannulated ductus choledochus twelve, eighteen, twenty-four, thirty and thirty-six hours after the administration of methylene blue by stomach tube contained little if any methylene blue. On the other hand, bile removed from the gallbladder at the same time invariably contained the dye. Bile collected from the cannulated ductus choledochus forty-two, forty-eight, sixty and seventy-two hours after the administration of methylene blue by stomach tube did not contain methylene blue. On the other hand, bile removed from the gallbladder contained the dye even after seventy-two hours in most instances.

In these feeding experiments, the methylene blue was introduced through a catheter into the stomach; consequently, the greater bulk of the dye which reached the liver must have come there by way of the portal vein. I have no information as to how soon and in what initial concentration methylene blue appears in the bile after oral administration and how long it takes to reach the highest concentration and what this highest concentration is. But I learned that in none of the thirty-four animals whose gallbladders were opened between the twelfth and the thirty-sixth hours after feeding the dye did the bile collected from the ductus choledochus contain methylene blue in a higher concentration than 1:23,000; as a matter of fact, in fourteen the bile did not contain any methylene blue. Yet the bile in the gallbladder contained the dye in concentrations between 1:1,200 and 1:10,000 in nineteen of these animals and between 1:10,000 and 1:25,000 in eleven. The results in the forty-two, forty-eight, sixty and seventy-two hour groups of thirty-two animals are uniform. As mentioned before, in none of the animals

did the bile collected from the cannulated ductus choledochus contain any methylene blue. Yet at this time, in more than half of the cases, the bile in the gallbladder contained the dye in concentrations ranging between 1 : 4,850 and 1 : 26,000.

From the feeding experiments it was learned that ingested methylene blue appears in the bile and is excreted for some time, during which the pure bile in the gallbladder is gradually replaced by the dye containing bile. Since the gallbladder mucosa is apparently resorbing the dye less rapidly than it resorbs bile, the dye accumulates and stays there.

In addition to all that has been said, attention should be called also to the fact that the amount of bile delivered through the cannulated ductus choledochus during an experimental period of six hours averages about 10 cc. per hour, that is, the liver of a rabbit weighing 3 Kg. produces 240 cc. of bile per day, a conservative estimation. The average capacity of the gallbladder of the rabbit is about 3 cc. Furthermore, in the feeding experiments the animals were kept on their usual diet, and there was always food in their cages. Under these conditions, it is hard to conceive how methylene blue could remain in the gallbladder of an animal for a period of at least forty-two hours during which not less than 420 cc. of bile not containing the dye could have come from the liver, unless one gives up the idea that the function of the gallbladder is to empty and to refill. The tenacity with which the dye is retained in the biliary vesicle long after the liver has ceased to produce bile containing the dye is surely one of the strongest arguments favoring the assumption that bile does not leave the gallbladder through the cystic duct under ordinary conditions. This circumstance, of course, calls for a change in the current conception of stasis in the gallbladder.

If resorption is the principal function of the biliary vesicle, stagnation in the gallbladder may be due either to an abnormal composition of the bile or to a disturbed resorptive function of the gallbladder mucosa. The site of the process leading to stasis in the gallbladder may be, of course, in the liver or in the gallbladder, or in both the liver and the gallbladder.

If the stasis in the gallbladder is due to a disturbed or altered functioning of the liver, that is, if the gallbladder is intact but unable to remove by resorption all that is poured into it with the bile, one may speak of a hepatogenous stasis in the gallbladder. The experiments with methylene blue furnish a striking example of such a hepatogenous stasis in the gallbladder.[45] With the bile from the liver a substance, methylene blue, is poured into the gallbladder; the mucosa of the latter apparently cannot resorb the dye fast enough to cause its rapid disappearance, and so the dye stays there for days. It is evident that much the same thing happens when the sodium salt of tetraiodophenolphthal-

ein is administered for cholecystography. Both of these examples of hepatogenous stasis in the gallbladder support the idea that something of the same order happens in cases of marked cholesterolemia, when the cholesterol content of the bile is correspondingly exaggerated. Apparently because of the increased output of cholesterol by the liver, the mucosa of the gallbladder becomes, so to speak, saturated with the lipoid substances which it has resorbed from the bile.[46] In such conditions, the cholesterol content of the bile in the gallbladder becomes greater and greater, and while the other bile constituents, those holding the cholesterol in solution, are being resorbed, the concentration finally may reach a point at which the cholesterol will crystallize out at the slightest provocation.

If the stasis in the gallbladder is caused by intrinsic functional disturbances or demonstrable pathologic conditions of the gallbladder itself, with the functioning of the liver more or less unimpaired, one may speak of a cystogenous stasis in the gallbladder. A variety of processes, such as acute, subacute and chronic inflammations, new growths, and the like, might lead to such a condition of the viscus.

CLASSIFICATION OF GALLSTONES

Perhaps the most convincing evidence for the existence of these two types, the hepatogenous and the cystogenous stasis, is furnished by the concretions usually found in these conditions. The chemical composition and the architecture of gallstones permit their ready classification into three groups.[47]

Group I is the group of "pure gallstones," that is, those consisting purely or mainly of one of the stone-forming constituents of the bile, such as (*a*) cholesterol, (*b*) biliary pigments (calcium bilirubinate) and (*c*) calcium carbonate. For the formation of all of these so-called "pure gallstones," the liver is perhaps primarily responsible. At least stones of pure cholesterol usually occur in normal gallbladders the mucosa of which may show signs of resorption of cholesterol, and this is to be regarded as evidence of the attempt of the mucosa of the gallbladder to remove the excess of cholesterol in the content of the vesica fellea. Stones composed wholly of pigment, that is, those consisting of calcium bilirubinate, are believed to form in the finer intrahepatic biliary ducts. They might be found then, of course, in gallbladders that are shown microscopically to be intact. The small concretions of calcium carbonate also occur in gallbladders in which pathologic changes are not demonstrable. It is therefore reasonable to assume that some transient abnormal composition of the bile leads to their formation.

Group II is the group of the "mixed gallstones," that is, those consisting purely or mainly of at least two of the constituents of the "pure

gallstones." Here belong (*a*) the stones consisting of cholesterol and calcium carbonate, (*b*) the stones consisting of cholesterol and calcium bilirubinate, (*c*) the stones consisting of calcium bilirubinate and calcium carbonate T, and (*d*) the stones consisting of cholesterol, calcium bilirubinate and calcium carbonate. The formation of these, so-called "mixed gallstones," has generally been associated with infection. Infection and inflammation damage the mucosa of the gallbladder so that not all of the constituents of the bile are resorbed. Whatever physicochemical explanation [48] is given for the process of formation of the "mixed gallstones" in inflamed gallbladders, the fact remains that the retention of the stone-forming constituents of the bile is due in the first place to a diseased condition of the gallbladder. Thus, "mixed gallstones" are formed in cystogenous stasis in the gallbladder, the stagnation being responsible for the formation of the stones and the infection for the stagnation.

It is evident that when a hepatogenous stasis in the gallbladder which has led to the formation of pure gallstones precedes a cystogenous stasis, "combined gallstones" form, which have a nucleus formed by one of the members of the group of "pure gallstones" and have a shell formed by one of the members of the group of "mixed gallstones." If, on the other hand, a cystogenous stasis in the gallbladder which has led to the formation of mixed gallstones is followed by a hepatogenous stasis, "combined gallstones" form, which have a nucleus formed by one of the members of the group of "mixed gallstones" and a shell formed by one of the members of the group of "pure gallstones."

The story of the formation of gallstones is then, briefly, as follows: A disturbed functioning of the gallbladder or an abnormal composition of the bile, or both, lead to a stagnation in the gallbladder of stone-forming constituents of the bile, the result of which is the formation of gallstones. The type of the concretion or concretions formed depends on the kind of biliary stasis which produced them. In a hepatogenous stasis in the gallbladder "pure gallstones" form, in a cystogenous stasis "mixed gallstones" form, and in an alternating stasis, "combined gallstones" form. Thus, gallstones can tell the story of the gallbladder; the story of a gallbladder, on the other hand, cannot be told unless its contents are known.

BIBLIOGRAPHY

1. Mann, F. C.: The Functions of the Gallbladder, Physiol. Rev. **4**:251, 1924.

2. Haberland, H. F. O.: Studien an den Gallenwegen, Arch. f. klin. Chir. **130**:625, 1924.

3. Rost, Franz: Pathologische Physiologie des Chirurgen, Leipzig, F. C. W. Vogel, 1925.

4. Lütkens, Ulrich: Aufbau und Funktion der extrahepatischen Gallenwege, Leipzig, F. C. W. Vogel, 1926.

5. Chiray, M., and Pavel, I.: La vésicule biliaire, Paris, Masson et Cie, 1927.

6. Pfuhl, Wilhelm: Beitrag zur physiologischen Anatomie der Gallenblase, Arch. f. klin. Chir. **147**:490, 1927.

7. Westphal, K., and Schöndube, W.: Einige Bemerkungen zur Physiologie der extrahepatischen Gallenwege, Klin. Wchnschr. **6**:2417, 1927.

8. Boyden, Edward A.: Concerning the Prevalent Denial of Functions Long Attributed to the Gall Bladder, Surg. Gynec. Obst. **46**:30, 1928.

9. Blond, Kasper: Eine neue Arbeitshypothese zur Klärung der Gallenwegsprobleme, Arch. f. klin. Chir. **149**:662, 1928.

10. Babkin, B. P.: Die äussere Sekretion der Verdauungsdrüsen, Berlin, Julius Springer, 1928.

11. Körte, Werner: Die Erkrankungen der Gallenwege, Dresden and Leipzig, Theodor Steinkopff, 1928.

12. Moynihan, Berkeley: Addresses on Surgical Subjects, Philadelphia and London, W. B. Saunders Company, 1928.

13. Lyon, B. B. Vincent: Can the Gallbladder Empty Through Duodenal Biliary Drainage? Is the Gallbladder the Source of "B" Bile? Arch. Int. Med. **43**:147 (Feb.) 1929.

14. Whitaker, Lester R.: Problems in Normal and in Abnormal Physiology of the Gallbladder, Arch. Surg. **18**:1783 (April) 1929.

15. Rolleston, Humphry; and McNee, John William: Diseases of the Gall-Bladder and Bile-Ducts, London, Macmillan and Co., 1929.

16. Berg, John: Studien über die Funktion der Gallenwege unter normalen und gewissen abnormen Verhältnissen, Acta chir. Skandinav. Supp. **2**:1, 1922.

17. Berg, John: Einleitungsvortrag zum Thema "Gallensteinleiden," Arch. f. klin. Chir. **126**:329, 1923.

18. Aschoff, L.: Ueber Orthologie und Pathologie der extrahepatischen Gallenwege, Arch. f. klin. Chir. **126**:233, 1923.

19. Aschoff, Ludwig: Lectures on Pathology, New York, Paul B. Hoeber, Inc., 1924.

20. Rous, Peyton; and McMaster, Philip D.: The Concentrating Activity of the Gall Bladder, J. Exper. Med. **34**:47, 1921.

21. Aschoff, L., and Bacmeister, A.: Die Cholelithiasis, Jena, Gustav Fischer, 1909.

22. Halpert, Béla: Neue Wege in der Gallenblasenforschung: I and II, Med. Klin. **20**:408 and 1830, 1924.

23. Sweet, J. E.: The Gall-Bladder; Its Past, Present and Future, Internat. Clin. **1**:187, 1924.

24. Virchow, R.: Ueber das Epithel der Gallenblase und über einen intermediären Stoffwechsel des Fettes, Virchows Arch. f. path. Anat. **11**:574, 1857.

25. Graham, Evarts A., and Cole, Warren H.: Roentgenologic Examination of the Gallbladder, J. A. M. A. **82**:613 (Feb. 23) 1924.

26. Graham, Evarts A.; Cole, Warren H.; Copher, Glover H., and Moore, Sherwood: Diseases of the Gall Bladder and Bile Ducts, Philadelphia, Lea and Febiger, 1928.

27. Boyden, Edward A.: A Study of the Behavior of the Human Gall Bladder in Response to the Ingestion of Food; Together with Some Observations on the Mechanism of the Expulsion of Bile in Experimental Animals, Anat. Rec. **33**:201, 1926.

28. Blond, Kasper: Footnote 9. Zum Entlehrungsmechanismus der extrahepatischen Gallenwege, Deutsche med. Wchnschr. **54**:778, 1928.

29. Boyden, Edward A.: An Analysis of the Reaction of the Human Gall Bladder to Food, Anat. Rec. **40**:147, 1928.

30. Whitaker, Lester R.: The Mechanism of the Gall Bladder, Am. J. Physiol. **78**:411, 1926.

31. Higgins, G. M., and Mann, F. C.: Observations on the Emptying of the Gall Bladder, Am. J. Physiol. **78**:339, 1926.

32. Hamrick, Robert A.: The Emptying of the Gall Bladder: An Experimental Study, Am. J. M. Sc. **174**:168, 1927.

33. Ivy, A. C., and Oldberg, Eric: A Hormone Mechanism for Gall Bladder Contraction and Evacuation, Am. J. Physiol. **84**:599, 1928.

34. Heister, Laurentius: Compendium Anatomicum, Amsterdam, 1723.

35. Löhner, L.: Gallen- und Gallenwegstudien I. Zur Füllungs- und Entleerungsmechanik der Gallenblase und über die Funktion der Valvulae Heisteri, Arch. f. d. ges. Physiol. **211**:356, 1926. Mentzer, Stanley H.: The Valves of Heister, Arch. Surg. **13**:511 (Oct.) 1926. Sweet, J. E.: The Importance to Surgery of the Cystic Duct, Am. J. Surg., new series, **3**:274, 1927.

36. Burget, G. E.: The Regulation of the Flow of Bile, Am. J. Physiol. **81**:422, 1927.

37. Halpert, Béla: Morphological Studies on the Gall-Bladder: I. A Note on the Development and the Microscopic Structure of the Normal Human Gall-Bladder, Bull. Johns Hopkins Hosp. **40**:390, 1927.

38. Wislocki, George B.: Observations on the Gross and Microscopic Anatomy of the Sloths, J. Morphol. & Physiol. **46**:317, 1928.

39. Boyden, Edward A.: The Accessory Gall-Bladder; an Embryological and Comparative Study of Aberrant Biliary Vesicles Occurring in Man and the Domestic Mammals, Am. J. Anat. **38**:177, 1926.

40. Halpert, Béla; and Lewis, Julian H.: Experimental Studies on the Isolated Gall Bladder of the Dog, Anat. Rec. **42**:50, 1929.

41. Halpert, Béla: A Note on the "True Luschka Ducts" and the "Rokitansky-Aschoff Sinuses" of the Human Gall-Bladder, Anat. Rec. **32**:232, 1926.

42. Halpert, Béla: Morphological Studies on the Gall-Bladder: II. The "True Luschka Ducts" and the "Rokitansky-Aschoff Sinuses" of the Human Gall-Bladder, Bull. Johns Hopkins Hosp. **41**:77, 1927.

43. Halpert, Béla; and Hanke, Milton T.: Observations on the Function of the Gall Bladder, Am. J. Physiol. **88**:351, 1929.

44. Mann, Frank C.: A Physiologic Consideration of the Gallbladder, J. A. M. A. **83**:829 (Sept. 13) 1924. Halpert, Béla; and Hanke, Milton T.: Some Observations on the Excretion of Certain Chemicals by the Biliary System of the Rabbit, Anat. Rec. **42**:49, 1929.

45. Halpert, Béla; and Hanke, Milton T.: The Excretion of Methylene Blue (Methylthionine Chloride, U.S.P.) by the Biliary System of the Rabbit; Its Significance for the Conception of Hepatogenous Stasis in the Gallbladder, Arch. Path. **7**:473, 1929.

46. Halpert (footnote 37). Boyd, William: Studies in Gall-Bladder Pathology, Brit. J. Surg. **10**:337, 1923. Mentzer, S. H.: Cholesterosis of the Gallbladder, Am. J. Path. **1**:383, 1925.

47. Halpert, Béla: New Aspects of the Formation and Classification of Gallstones, Arch. Path. **6**:623 (Oct.) 1928.

48. Schade, H.: Die physikalische Chemie in der inneren Medizin, Dresden and Leipzig, Theodor Steinkopff, 1923. Lichtwitz, L.: Ueber die Bildung der Harn- und Gallensteine, Ergebn. d. inn. Med. u. Kinderh. **13**:1, 1914.

FIBROMA OF THE VULVA CONTAINING AN EPITHELIAL INCLUSION CYST *

LEO BRADY, M.D.
BALTIMORE

Fibromas arising from the external genitalia in women are by no means common. In a study of 5,000 gynecologic cases tabulated at the Michigan University Hospital, in 1905, Burr [1] did not find a single case of vulvar fibroma. In 1917, Leonard [2] was able to find records of only six such tumors among the 23,000 patients admitted to the gynecologic department of the Johns Hopkins Hospital. Up to the present time, less than 175 fibromas of the vulva have been reported in all medical literature.

The majority of these growths arise in the subcutaneous connective tissue, but quite a large group of them originate in the extraperitoneal portion of the round ligament. It has long been known that the round ligament of the uterus, after traversing the entire length of the inguinal canal, emerges from the external inguinal ring and ends by breaking up into a number of diverging fibrous bands most of which become lost in the subcutaneous tissue of the labium majus, while a few find attachment to the pubic spine. In a certain number of cases of fibromas of the vulva, it is possible to feel a firm round cord running through the tumor, and, by following this cord upward, to trace it directly to one of these terminal fibers of the extraperitoneal portion of the round ligament, thus clearly demonstrating the point of origin of the growth. According to Leonard, as many as 33 per cent of these tumors arise in this manner.

There have been reported a moderate number of cases of fibrous tumors originating in the subperitoneal connective tissue and appearing at the vulva, and a few rare fibromas of the vulva have been supposed to arise in the connective tissue of the rectovaginal septum or of Bartholin's glands, or to have started in a hematoma. The tumors arising in the subperitoneal connective tissue and making their way to the vulva form an especially interesting group of neoplasms, because of the tremendous size attained by some of them. In 1905, Whitney and Harrington,[3] published a comprehensive article on subperitoneal fibro-

* Submitted for publication, Nov. 22, 1928.

1. Burr, T. S.: Report of a Case of Fibroma of the Vulva, New York M. J. **81**:340, 1905.

2. Leonard, V. N.: Fibroid Tumors of the Vulva, Bull. Johns Hopkins Hosp. **28**:373, 1917.

3. Whitney, W. F., and Harrington, F. B.: Subperitoneal Pelvic Fibromata, Ann. Surg. **41**:823, 1905.

mas based on the literature of nineteen such cases. Specifically, these subperitoneal tumors are supposed to arise from the connective tissue of the true pelvis, thus differing from the so-called retroperitoneal growths which originate in the root of the mesentery, the region of the kidney and the false pelvis.

In 1912, Aichel,[4] reported a case of a fibrous tumor appearing at the vulva of an infant, and Esser [5] and Polaillon [6] each had a patient in whom a fibroma of the vulva arose after the menopause, but in the great majority of instances fibromas of the vulva have been noted in women in the child-bearing age. Many observers have for years commented on the periodic increase in size which these tumors undergo with each menstrual period, a phenomenon due to the increased blood supply to the vulva at that time. It has also been noticed that with each pregnancy there has usually been an increase in the rapidity of growth of the neoplasm.

When first seen, fibromas of the vulva usually appear as firm, smooth, round or oval nodules under the skin. As the growth increases in size, it may become pedunculated as a result of the constant pull of the tumor mass on the loose connective tissue in which it is embedded. When the patient is seen by the surgeon, there is often a definite pedicle, and the tumor presents a striking picture. The remarkable resemblance of some of these growths to a male scrotum has been noted frequently. The skin covering them is generally thick, and often between the menstrual periods it is thrown up into shallow folds. Both tumor and pedicle are frequently covered with hair. On palpation the tumors show the same firm consistence as fibromas elsewhere in the body, but if the circulation becomes impaired, they may become edematous and semifluctuant.

Fibromas of the vulva vary greatly in size, some of them remaining as small nodules while others grow to be tumors of enormous size. In 1851, Buckner [7] reported a mammoth growth which arose in the subperitoneal connective tissue and appeared at the vulva. It is said to have weighed 268 pounds (121.5 Kg.) and is probably the largest human tumor ever reported. In the Warren Anatomical Museum at Harvard University,[8] there is a daguerreotype made of this tumor while the patient was alive and also a detailed account of the history of the

4. Aichel: Rhabdomyom des Ligamentum rontundum des neugeborenen Mädchens, Zentralbl. Gynäk. **26**:57, 1912.

5. Esser: Zwei neue Fälle von gestielten Fibrom an den grossen Schamlippen, Inaug. Diss., Bonn, 1892.

6. Polaillon: Fibroma de la région inguinale droite, Gaz. Méd. de Paris **7**:229, 1891.

7. Buckner: Ohio State M. Tr., 1851.

8. Jackson, J. B.: A Descriptive Catalogue of the Warren Anatomical Museum, 1870, p. 642, no. 2982.

case and of the partial autopsy that was performed. As the abdominal viscera including the pelvic organs were all palpated through an opening made after death into the peritoneal cavity and found to be normal, there can be no doubt that the tumor arose extraperitoneally.

In 1917, Leonard, made an exhaustive study of all the recorded cases of fibromas of the vulva, giving in his article summaries of the gross and microscopic appearances in 100 cases that had been reported in the literature and reporting in detail the cases of six patients who had been treated in the Johns Hopkins Hospital. He showed that nearly one fifth of these tumors became sarcomatous. Hence, any sudden increase in rate of growth should be viewed with suspicion, and immediate surgical intervention is indicated.

Unless inflammatory or malignant changes occur, fibromas of the vulva produce few, if any, symptoms. If they are pedunculated they may cause some chafing of the skin with which they come in contact and thus interfere with locomotion. The large tumors may prevent coitus or become an obstacle at labor.

The diagnosis of fibromas of the vulva usually presents little difficulty. However, one must be careful not to mistake a tumor which originates in the extraperitoneal portion of the round ligament for a hernia. Nor should the possibility that these tumors may be adenomyomas instead of simple fibromas be forgotten. In 1896, Thomas Cullen [9] first described adenomyoma of the round ligament and emphasized the diagnostic importance of severe pain associated with these tumors at each menstrual period. Although fibromas of the vulva are apt to become swollen at each period, they do not cause the patient any severe pain at that time for there is no hemorrhage into the tumor such as occurs in an adenomyoma every time menstruation occurs.

REPORT OF CASE

Recently, I happened to have under my care a patient with a fibroma of the vulva. A report of this case may be of interest for two reasons: First, the growth probably belonged to that group of less common fibromas of the vulva which originate in the extraperitoneal portion of the round ligament; secondly, the tumor contained a long, tubular, epidermoid sac. In this respect, I believe, it was unique, as a rather careful study of the literature failed to reveal another instance of a tumor of the vulva containing a similar structure. The following is a brief report of the case:

History.—Mrs. G. H., aged 33, seen on March 12, 1928, had always had good general health. Her appetite was fair. She had not had indigestion or nausea.

9. Cullen, T. S.: Adenomyoma of the Round Ligament, Bull. Johns Hopkins Hosp. **7**:112, 1896.

The bowel movements had been regular, and she had not had any urinary symptoms. The menses had begun at 14 years; they had been regular and not associated with pain. There was no history of leukorrea. The patient had been married for thirteen years and had had three children, now 12, 10 and 4 years of age. She had had considerable difficulty with each labor, but only with the first were instruments used. She had not had any miscarriages. Ten years before I saw her, when her second child was only 2 weeks old, she first noticed a small, hard lump in the right groin, which since that time had been gradually increasing in size. She thought that with each menstrual period there was a definite change in the tumor—that as the period approached it became larger and softer and after the period smaller and firmer. However, she had never suffered any pain referable to it at the time of the menstrual period. Six weeks before the patient entered the hospital, while she was bending over, the tumor became caught between two metal objects and she, being unaware of this mishap, straightened herself up, thus causing the entire tumor to be strongly pinched and severely traumatized. For several days the growth was red, tender and swollen, but under boric acid compresses the inflammation subsided. As the patient had not had any menstrual periods for six months, she considered herself to be six months' pregnant.

Examination.—On March 12, 1928, the general physical examination gave essentially negative results. The breasts contained colostrum. A symmetrical, firm tumor could be felt arising from the pelvis and extending 1 fingerbreadth above the umbilicus. As the fetal heart could be heard, there was no doubt that the uterus was pregnant. Arising from the right side of the vulva, immediately above the spine of the pubis, was a pedunculated tumor mass, measuring 15 cm. from its origin to its tip. Near its point of origin the tumor had a firm, constricted neck, but toward its lower portion it widened out until it had a diameter of 5 cm. It was covered with thin skin, suggesting that of a male scrotum. Only the upper part of the sac was covered with hair. There was a linear scar running along the tumor, in the center of which healing had occurred in such a way as to cause some invagination of the edges of the skin and to give the scar a dimpled appearance. This scar probably was caused by the injury two months previously.

On examination one could feel within the tumor a firm, circular band of tissue which extended from 3 cm. of the distal end to within 4 cm. of the point of origin of the tumor. As it stopped several centimeters from the point of origin of the tumor, it could not, of course, be traced up into the inguinal canal. This structure, while not attached to the overlying skin, felt as if it were in the outer part of the tumor rather than in its center. When the patient stood, the tumor hung down to within 8 cm. of the patella (fig. 1). There was no impulse over the femoral or the inguinal ring. The two sides of the vulva below the insertion of the tumor were exactly alike. With the patient lying on her back, careful examination showed that the tumor arose directly at the external inguinal ring (fig. 2). The internal pelvic examination showed the patient to have a moderately relaxed vaginal outlet and a soft cervix. The uterus was the size of a six months' pregnancy. The rectal examination and the urine showed nothing abnormal.

Operation.—At St. Joseph's Hospital, March 15, 1928, under local anesthesia, an oval incision was made around its base and the tumor removed. A few small vessels had to be ligated. The edges of the incision were approximated with chromic catgut and a small protective drain introduced. The drain was removed on the next day, and the patient had an uneventful convalescence.

The baby was born on June 15, 1928. The labor was uneventful. A final examination on July 8, 1928, did not show evidence of any return of the growth; the general condition was excellent.

Fig. 1.—The tumor reaches to within a short distance of the patella. The resemblance to a male scrotum is striking.

Fig. 2.—The tumor can be seen to arise directly over the external inguinal ring. The scar with a dimple in its center can be seen.

Pathologic Report (Johns Hopkins Hospital).—The specimen consisted of an elongated tumor, which was contracted at one end and somewhat dilated at the other. The entire tumor was covered with skin, and over its upper portion there was a moderate amount of hair. There was a healed scar in the skin over the tumor and in its center was a dimple. A firm, round cord could be palpated in the growth. This ran from within a short distance from the contracted end of the tumor almost all the way to the dilated end. When the tumor was split in half, the hemisections presented the firm white surface of fibroma.

The cordlike structure felt in the tumor stood out plainly (fig. 3). At the upper end of the tumor it seemed to fade into the skin, while at the lower end it

Fig. 3.—The tumor split open. Some edema has developed in the lower dilated portion of the growth, which gives it a somewhat different appearance from the rest of the tumor. *a* marks the tube which was found in the tumor. Although not attached to the skin, this tube lies in the outer part of the tumor directly under the skin.

disappeared into the tumor itself. It was 6 cm. long and on cross-section showed a definite lumen which could be seen with the naked eye.

Microscopic sections taken from the tumor and the surrounding skin showed on the outside the normal squamous epithelium of the skin and below it the typical microscopic picture of a fibroma. The cordlike structure felt in the tumor was seen to be formed by a tube lined with several layers of squamous epithelium of

the same character as that of the skin on the outside of the tumor. The photomicrograph showed that this tube, while not attached to the skin, lay only a short distance below it (fig. 4). The tube had a lumen filled with debris, probably made up of desquamated epithelial cells. Some cornification of the internal layer of epithelium had occurred. There was a moderate accumulation of small round cells on the outside of this tube (fig. 5).

COMMENT

This fibroma of the vulva could not be traced directly into the inguinal canal. However, from the fact that it arose from a point

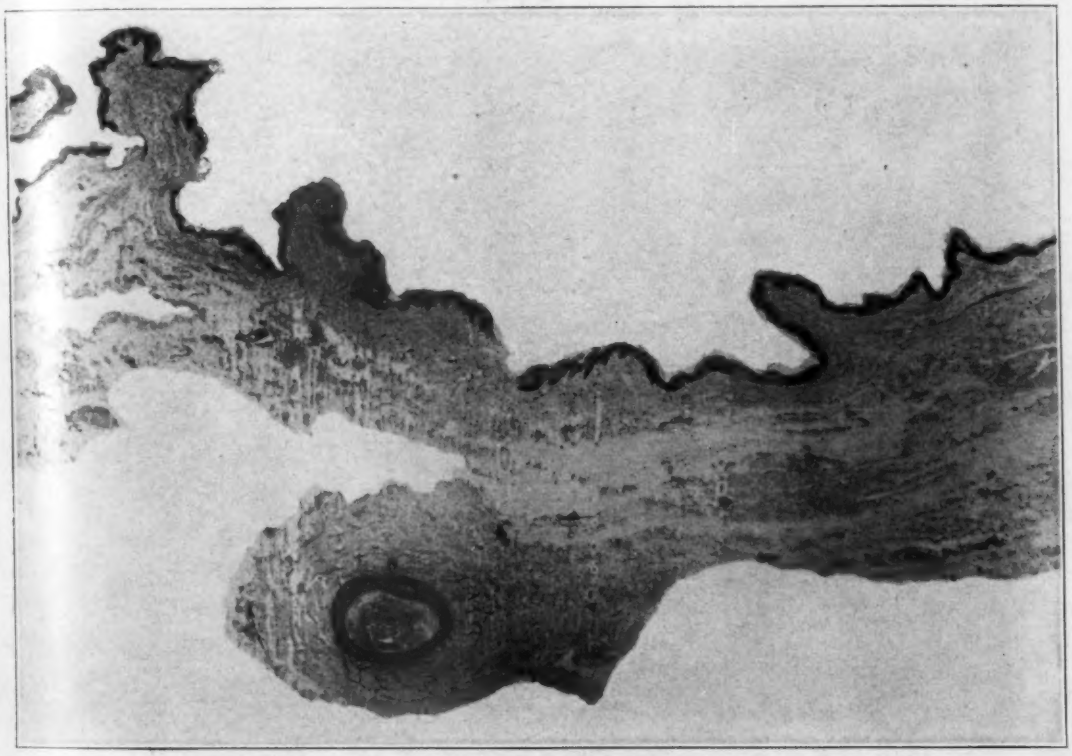

Fig. 4.—Photomicrographic appearance of the tumor. On the outside is the squamous epithelium of the skin. Below this is the fibroma. The tube lined with squamous epithelium lies directly under the skin.

directly over the external inguinal ring, just where the extraperitoneal portion of the round ligament breaks up into its terminal fibers, it seems more likely that this growth arose from one of these terminal fibers rather than from the fibrous elements found in the subcutaneous tissue.

It is difficult to find a satisfactory explanation for the occurrence of the tube with squamous epithelium that was found in this tumor. The tube was not the terminal portion of a hydrocele of the canal of Nuck,

for such a structure, being really a pouch of peritoneum, would have a lumen lined with cuboidal, columnar or flat epithelium and not with the squamous variety. There is nothing about this tube to suggest that it is a dermoid, nor does it resemble a hidradenoma, a definite type of neoplasm, first described by Pick [10] in 1904 and supposed to arise from

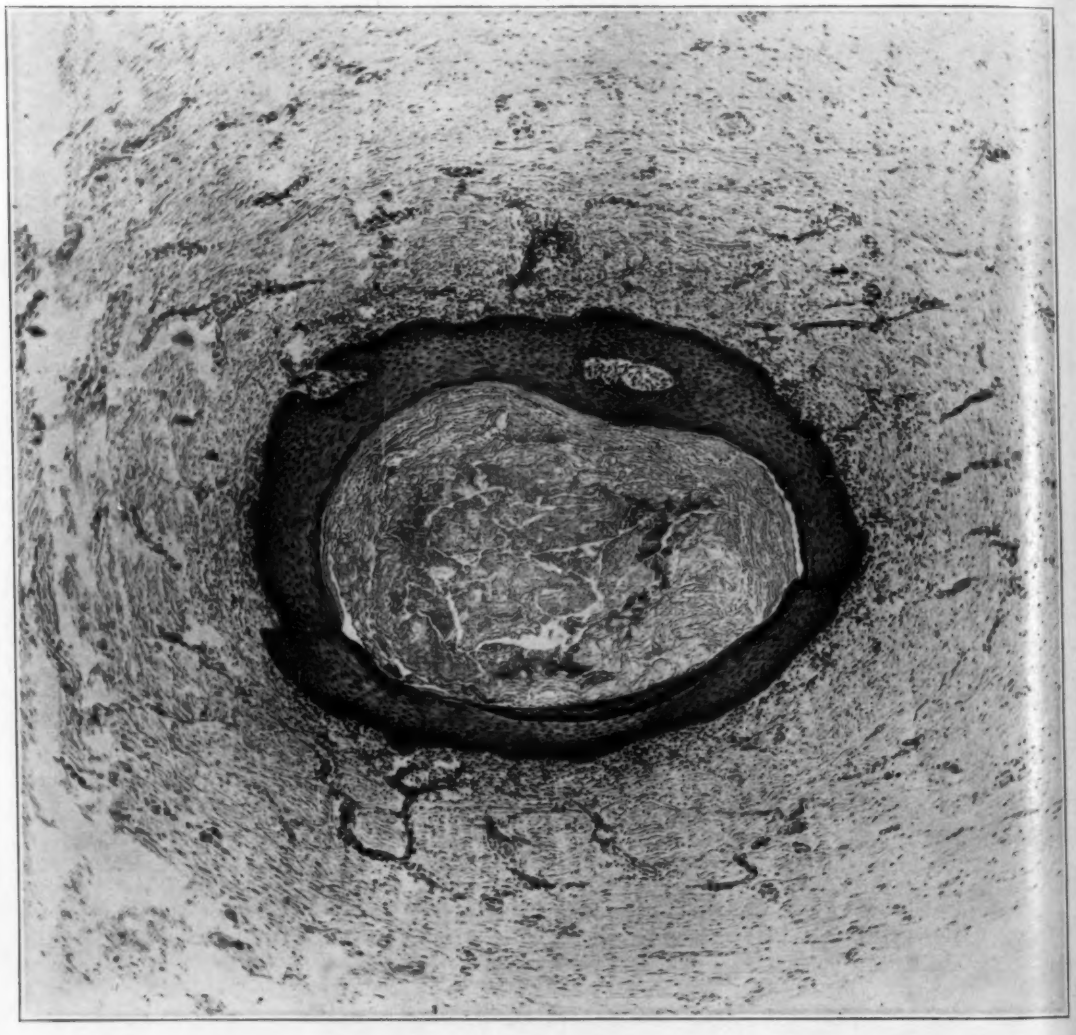

Fig. 5.—Photomicrographic appearance of the traumatic epithelial cyst or tube. The squamous epithelium is several layers deep. Some cornification of the internal layer of epithelium has occurred. The lumen of the tube is filled with debris. There is a moderate accumulation of small round cells on the outside of the tube.

10. Pick, Ludwig: Ueber Hidradenoma und Adenoma Hidradenoides, Virchows Arch. f. path. Anat. **175**:312, 1904.

the sweat glands of the vulva. Microscopically, hidradenomas suggest rather actively growing adenomas.

One theory for the occurrence of this epithelium lined tube in the fibroma is that as a result of trauma part of the outside skin was forced down into the tumor, and that this fragment of skin continued to grow and formed an epithelium lined tube in the tumor. This theory appears to be plausible because the tube was situated in the outer part of the tumor rather than in its center and was lined with squamous epithelium. Moreover, there was a definite history of the tumor being severely traumatized, and at this time part of the overlying skin may have been forced down into the tumor.

Although a careful search of the literature failed to reveal any other instances of a vulvar fibroma containing such a tube as was found in the case reported, quite a few instance of epidermoid inclusion cysts of the hand and fingers have been reported. As far back as 1855, Wernher [11] removed a tumor, which was probably of this nature, from the palm of a man's hand, but he considered it to be an atheroma. Many of the earlier investigators thought that these tumors developed from sweat glands, although this opinion necessitated the belief that glandular epithelium changed into squamous epithelium. However, in 1887, Franke [12] stated that quite a number of epithelial cysts of the skin previously reported had been wrongly called atheromas or dermoids, and for these cysts he proposed the name epidermoids. Even Franke, however, did not understand how these cysts are formed, since he spoke of them being of congenital origin, and it remained for Reverdin [13] to explain their etiology. He observed that these cysts almost always developed after an injury, such as a stab, pinch, bite or crush, and collected reports of thirty cases of epidermoid cysts from the literature in all of which there was a history of trauma with a later development of an epidermoid cyst below the injured skin.

On the experimental side Kaufman,[14] in 1884, and Gross,[15] in 1885, proved that loose pieces of skin could be implanted in the subcutaneous tissue of animals as well as in the abdominal cavity, and that these pieces of skin would continue to carry out their physiologic function, namely, that of the production of epidermis. They found that after a short time the implanted epidermis developed into a cyst.

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11. Wernher, A.: Das Atherome ein eingebolgtes Epitheliom, Virchows Arch. f. path. Anat. **8**: 22, 1855.

12. Franke, F.: Ueber das Atherom besonders mit Bezug auf sein Enstehung (das Epidermoid), Arch. f. klin. Chir. **34**: 507, 1887.

13. Reverdin, J. L.: Des kystes epidermigues des doights, Rev. med. de la Suisse Rom. **7**: 38, 1887.

14. Kaufman: Ueber Enkatarhaphie von Epithel, Virchows Arch. f. path. Anat. **97**:236, 1884.

15. Gross: Contribution a l'etude des tumeurs perlées, Paris, 1885.

Since the publication of these first articles on traumatic epithelial cysts of the hands, only occasional reports on this subject have appeared. In 1893, Bland Sutton [16] reported the case of an implantation cyst on the thumb of a girl, aged 18 years. In 1895, Wörz [17] reported three additional cases and summarized the literature on these tumors up to that time. During the last few years the best article on this subject was published in 1921 by Carossin,[18] an Italian observer, who, in addition to covering thoroughly the entire subject and reviewing the literature, reported the case of a traumatic epithelial cyst occurring on the palmar surface of the middle finger.

Epidermoid inclusion cysts have been found in one other locality besides the hand and fingers, namely, the vagina. While for many years they have been occasionally found and reported here, it was not until 1899 that Stokes [19] correctly explained their etiology. Previous to the publication of his article it had been noticed that cysts in the posterior vaginal wall occasionally followed traumas to the vagina, such as occur in perineal tears or when a perineal operation is performed, but he was the first to stress the point that these cysts developed only when some of the surface epithelium is included within the edges of the wound. It is easy to understand how in doing a perineorrhaphy a surgeon, in denuding the vaginal mucosa, might accidentally miss small bits of mucous membrane and then, in bringing the tissues together, bury these islands of vaginal mucosa deep down in the tissue where later they might develop into vaginal epidermoid cysts. In 1905, Thomas Cullen [20] showed that in twenty-four instances of epidermoid cysts occurring in the lower lateral or posterior vaginal wall, there was a history of a lacerated perineum and in five out of the twenty-four the perineal tear extended into the rectum.

Some recent experimental work performed on dogs by Davis and Traut [21] is of special value to those interested in the formation of epithelium lined cysts. These investigators cut whole thickness grafts, placed them on one of the abdominal muscles from which the fascia had been stripped and sutured them in position under approximately the

16. Sutton, Bland: A Clinical Lecture on Some Unusual Tumors, Brit. M. J. **1**:461, 1895.

17. Wörz, A.: Ueber traumatische Epithelcysten, Ztschr. f. klin. Chir. **18**:753, 1897.

18. Carossin, G.: Le cisti epitheliali traumatische del palmo dello mano, Gior. di. med. ferrov. Prato. **1**:20, 1921.

19. Stokes, J. E.: The Etiology and Structure of True Vaginal Cysts, Johns Hopkins Hosp. Rep. **7**:109, 1899.

20. Cullen, T. S.: Vaginal Cysts, Bull. Johns Hopkins Hosp. **16**:207, 1905.

21. Davis, J. S., and Traut, H. F.: The Production of Epithelial-Lined Tubes and Sacs, J. A. M. A. **86**:339 (Jan. 30) 1926.

tension under which they had been as parts of the external skin. The result of this procedure was the formation of either an epithelium lined cyst or a tube, according to the shape of the buried graft. The epithelium of the graft grew outward from the margins and completely covered the contiguous tissues. As the two margins met, either a tube or a sac was formed. Microscopic examination of cross-sections of these tubes or sacs showed not only that epithelium surrounded the lumen but that this was several cells deep and in a viable condition. In these experiments, Davis and Traut found it took about twenty days for the margins of the buried skin grafts to unite and form tubes. The maximum development of the epithelium lining the tubes was reached in forty days, after which it began to degenerate, probably as a result of the pressure exerted by the fluid secreted within the cyst.

In my case, the fibroma of the vulva had been severely pinched six weeks before operation. It seems possible that at that time an elongated strip of skin was forced down into the tumor and that the edges of this strip of skin continued to grow, united and formed an epithelium lined tube.

SUMMARY

A large fibroma of the vulva is recorded, which probably had originated from one of the terminal fibers of the extraperitoneal portion of the round ligament.

The tumor contained within it a tube lined with several layers of squamous epithelium. Its development is probably to be explained as follows: As the result of trauma (a severe pinch), a strip of skin was forced down into the tumor and the edges of the enclosed skin; it continued to grow, united and formed an epithelium lined tube.

EXPERIMENTAL ILEUS

I. HIGH OBSTRUCTION WITH THE BILIARY, PANCREATIC AND DUODENAL SECRETIONS SHORT-CIRCUITED BELOW THE OBSTRUCTED POINT *

HILGER PERRY JENKINS, M.D.
CHICAGO

The cause of death in acute intestinal obstruction has not yet been definitely established. Most investigators are of the opinion that it is the result of absorption of a toxin in the obstructed bowel, which may be formed either in the mucosa of the bowel and absorbed directly [1] or in the lumen of the intestine as the result of the action of normal digestive secretions, abnormal or perverted secretions [2] or of bacteria [3] on the stagnated contents of the obstructed bowel. The absorption of this toxic substance within the intestine is thought to be influenced by the degree of damage to the mucosa from distention,[3] and by increased intraviscus pressure.[4] It is believed by some that the toxic element can be isolated, and that it is a split protein product, which, when injected into normal animals, produces a severe toxemia and death.[5] On the other hand, there are a few who feel that death is due to a marked disturbance of the water and mineral balance of the body from dehydration and loss of sodium and chloride ions.[6] A thorough review and analysis of the experimental work on intestinal obstruction is given in Cooper's [7] recent article.

To determine the rôle of the biliary, pancreatic and duodenal secretions in the rapid death from high intestinal obstruction, which usually occurs in from two to eight days in the dog,[8] an experiment was devised

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* From the Department of Surgery, the University of Chicago.

1. Whipple; Stone, and Bernheim: J. Exper. Med. **17**:307, 1913.

2. Ellis: Ann. Surg. **75**:429, 1922.

3. Murphy, F. T., and Brooks, B.: Intestinal Obstruction, Arch. Int. Med. **15**:392 (March) 1915. Dragstedt; Dragstedt; McClintock, and Chase: J. Exper. Med. **30**:109, 1919.

4. Stone, H. B., and Firor, W. M.: Absorption in Intestinal Obstruction, Soc. Proc., J. A. M. A. **84**:141 (Jan. 10) 1925. Owings; McIntosh; Stone, and Weinberg: Intral Intestinal Pressure in Obstruction, Arch. Surg. **17**:507 (Sept.) 1928. Stone: Am. J. Surg. **1**:282, 1926.

5. Whipple; Rodenbaugh, and Kilgore: J. Exper. Med. **23**:123, 1916.

6. McIver, M. A., and Gamble, J. L.: Body Fluid Changes Due to Upper Intestinal Obstruction, J. A. M. A. **91**:1589 (Nov. 24) 1928.

7. Cooper, H. S. F.: Cause of Death in High Obstruction, Arch. Surg. **17**: 918 (Dec.) 1928.

8. Haden, R. L., and Orr, T. G.: Obstruction of Jejunum: Effect on Sodium Chloride in Chemical Changes in Blood of Dogs, Arch. Surg. **11**:859 (Dec.) 1925.

which permitted these three secretions to be short-circuited below the point of obstruction. This was done by operations in either two or three stages. Six dogs with obstruction produced in this way lived from twelve to thirty-three days.

EXPERIMENTAL WORK

Dog 337.—First Stage: After pylorectomy, the end of the duodenum was closed. The jejunum was sectioned about 8 cm. beyond the duodenum. The open end of the distal part was closed and then an end-to-side anastomosis was made between it and the open end of the stomach. The proximal part was anastomosed to the upper portion of the ileum by the end-to-side method. In this way the stomach drained into the jejunum, and the duodenum into the ileum.

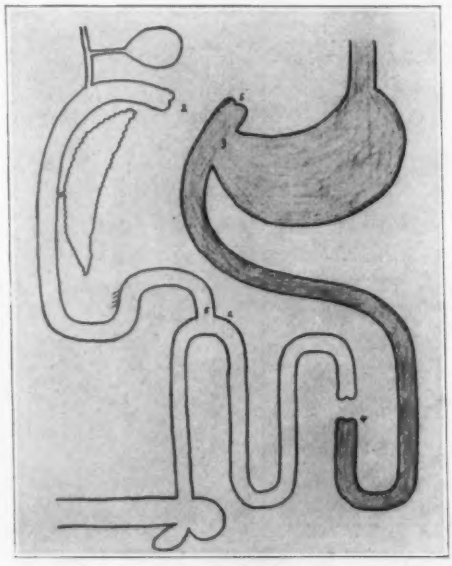

Fig. 1.—Two-stage procedure. First: pylorectomy, 2; section of the jejunum, 5; anastomosis of proximal part of jejunum to ileum, 1; anastomosis of distal part to stomach, 3; second: obstruction of the jejunum, 4.

Second Stage: Three weeks later, an obstruction was produced in the jejunum by sectioning the bowel 75 cm. from the stomach and closing the ends (fig. 1).

After obstruction was produced, the general condition of the dog was excellent. It walked and ran about normally, drank water freely, ate food sometimes, vomited occasionally and passed several small stools. On the sixteenth day it weakened markedly and death occurred on the seventeenth day. The weight gradually declined from 11.4 to 7.6 Kg., a total loss of 33 per cent, an average loss of 0.22 Kg. per day, or 1.95 per cent per day. The blood chemistry showed a fall in total chlorides estimated as sodium chloride from 525 to 395 mg. per hundred cubic centimeters. There was a rise in carbon dioxide capacity from 49 to 76, and in nonprotein nitrogen from 30 to 39 mg. per hundred cubic centimeters. There was little change in the content of urea nitrogen which varied from 14 to 15 mg. per hundred cubic centimeters (fig. 2). At autopsy, the abdominal cavity

was found filled with several ounces of gray, purulent fluid. About 18 cm. of the end of the bowel beyond the point of obstruction had undergone intussusception. This part was distended and discolored and contained a small area of gangrene with perforation. The stomach and the jejunum, which was anastomosed to it, were distended with a thick gray fluid. The lungs and other organs were grossly normal. Death was due to general peritonitis following intussusception and perforation of the bowel.

Dog 515.—First Stage: This stage was the same as for dog 337, except that the proximal part of the sectioned jejunum was anastomosed to the ileum by the side-to-side method after the open end had been closed.

Second Stage: Twelve days later, obstruction was produced by sectioning the jejunum 26 cm. from the stomach.

The general condition of the dog following obstruction was good until the ninth day, when it began to show signs of weakening, which progressed until its death

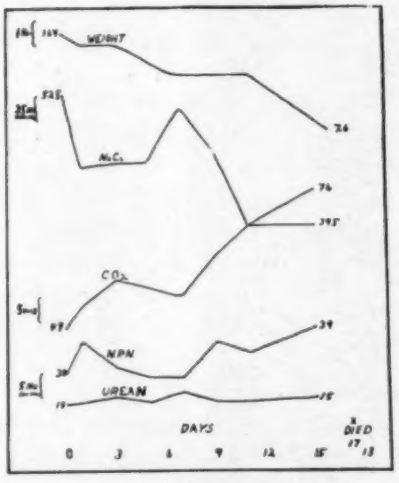

Figure 2

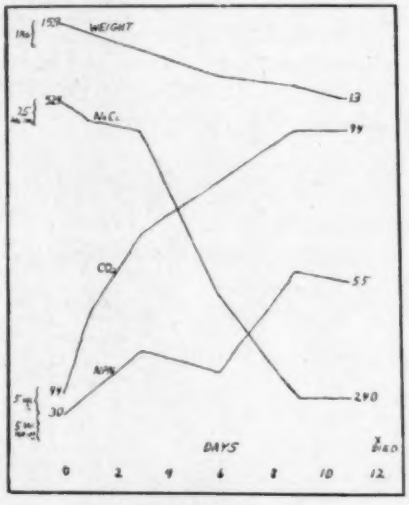

Figure 3

Fig. 2.—Weight and chemistry readings for dog 337; obstruction at 76 cm.; death on the seventeenth day.

Fig. 3.—Weight and chemistry readings for dog 515; obstruction at 26 cm.; death on the twelfth day.

on the twelfth day. Drinking, eating, vomiting and passage of stools occurred as in dog 337. The weight declined from 16 to 13 Kg., which was a loss of 19 per cent, an average of 0.27 Kg. or 1.7 per cent per day. The blood chemistry showed a fall in sodium chloride from 524 to 240, a rise in carbon dioxide capacity from 44 to 94 and in nonprotein nitrogen from 30 to 55 (fig. 3). At autopsy the stomach and jejunum down to the point of obstruction were distended. The remaining bowel was partially collapsed. The organs were grossly normal, except for consolidation in the lower lobe of the right lung. Death was due to bronchopneumonia.

Dog 983.—First Stage: A lateral anastomosis was made between the middle of the ileum and the jejunum just beyond the duodenum.

Second Stage: One week later, the pylorus was resected and the open ends of the stomach and duodenum were closed. An anterior gastro-enterostomy was made, the jejunum just beyond the lateral anastomosis being used. The proximal portion of the jejunum was sectioned between the two anastomoses, and the ends were closed.

Third Stage: Three weeks later, an obstruction was produced by sectioning the bowel above the entero-anastomosis, 150 cm. below the stomach (fig. 4).

The general behavior of the dog following obstruction was similar to that of the two animals described. Death occurred on the seventeenth day. The weight declined from 20.6 to 15 Kg., a total loss of 32 per cent and an average loss of 0.39 Kg. or 1.8 per cent per day. The blood chemistry showed a gradual fall in sodium chloride from 547 to 271 and a rise in carbon dioxide capacity from 44 to 78. The content of nonprotein nitrogen changed only slightly during the first two weeks,

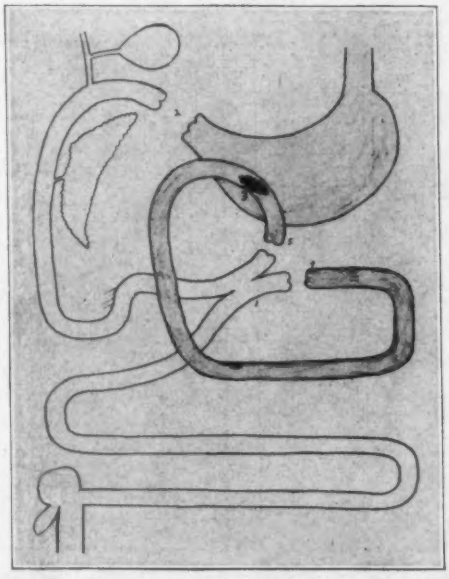

Fig. 4.—Three-stage procedure. First: (dogs 983, 493, 492 and 489) lateral anastomosis between upper part of jejunum and upper ileum. Second: (dog 983) pylorectomy, 2, anterior gastro-enterostomy, 3, and interruption of jejunum, 5; (dogs 493, 492 and 489) pylorectomy, 2, and anterior gastro-enterostomy. Third: (dog 983) obstruction of the bowel, 4; (dogs 493, 492 and 489) interruption of jejunum, 5, and obstruction of jejunum, 4.

but rose abruptly just before death to 127. The urea nitrogen also changed little, except for a terminal rise to 81 (fig. 5). Autopsy showed a dilatation of the terminal 15 cm. of the obstructed bowel without any marked change above this or in the stomach. The only other gross change was consolidation in the lower lobe of the right lung. The immediate cause of death was bronchopneumonia.

Dog 493.—First Stage: The procedure was the same as for dog 983, except that the upper part instead of the middle part of the ileum was used. The dog weighed 20.8 Kg.

Second Stage: The weight was 21.6 Kg. This stage was three weeks later and was the same as for dog 983, except that the jejunum was not sectioned between the two anastomoses.

Third Stage: The weight was 21.3 Kg. This stage was done two and a half weeks later and consisted of interruption of the upper jejunum between the entero-anastomosis and the gastro-enterostomy, and obstruction of the jejunum 90 cm. from the stomach (fig. 4).

The general behavior of the animal was not markedly changed following the obstruction, except that it appeared less lively. It was able to walk about all right until the twenty-fifth day, when it appeared to be growing weak. Weakness progressed during the next day, and death occurred on the morning of the twenty-seventh day. The daily intake of water by mouth was from 400 to 500 cc., to which about 1 Gm. of sodium chloride was added every third day, and dextrose

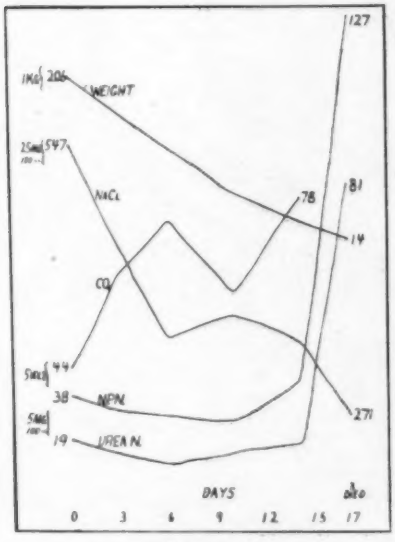

Figure 5

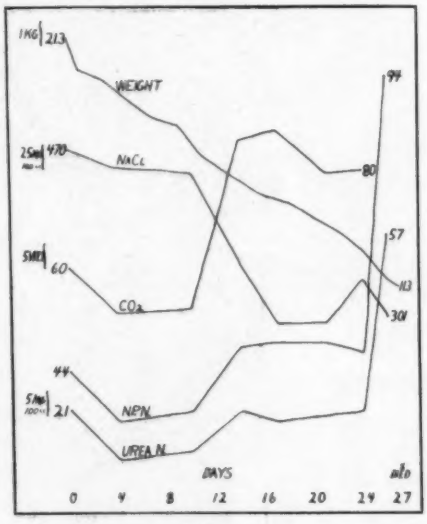

Figure 6

Fig. 5.—Weight and blood chemistry readings for dog 983; obstruction at 150 cm.; death on the seventeenth day.

Fig. 6.—Weight and blood chemistry readings for dog 493; obstruction at 90 cm.; death on the twenty-seventh day.

occasionally. Small feedings of meat were given about twice a week. Vomiting occurred only about twice a week. The urinary output was from 200 to 300 cc. per day. Small black or brown stools were passed on an average of two or three times a week. The weight gradually declined from 21.3 to 11.6 Kg., which was a loss of 45 per cent, an average of 0.37 Kg. or 1.75 per cent per day. The blood chemistry showed a fall in sodium chloride from 470 to 301 and a rise in carbon dioxide capacity from 59 to 80, in nonprotein nitrogen from 44 to 94, and in urea nitrogen from 21 to 57, the latter two making the most abrupt rise just before death. During the first ten days of the obstruction, the carbon dioxide and nonprotein and urea nitrogen showed a moderate fall (fig. 6). Autopsy revealed a

marked dilatation of the stomach and of the obstructed loop of jejunum which was most marked in the lower third, where it measured from 4 to 5 cm. in diameter. In addition, there was an intussusception of the ileum, 15 cm. below the anastomosis with the jejunum, which had produced a complete obstruction at this point. This made a closed intestinal loop into which the pancreatic, biliary and duodenal secretions emptied. The loop was as markedly distended as the obstructed jejunum. Beyond this intussusception the bowel was only partially collapsed down to a second point where another telescoping had occurred. Beyond this point it was completely collapsed (fig. 7). The stomach contained 200 cc. of a thick gray material and the jejunum 430 cc. of the same type of substance, which was 69 per cent sediment. In the duodenum there was 150 cc. of a brown watery material which was 25 per cent sediment. The omentum and mesentery were devoid of any adipose tissue. The musculature was markedly atrophied. The mesenteric lymph glands were enlarged, and one of these exuded thick purulent

Fig. 7.—Distention of stomach and jejunum down to obstruction at *B* in dog 493. Distention of duodenum and jejunum to point of interruption at *A* and of ileum down to *C* where first intussusception occurred producing obstruction, intussusception also at *D*.

material when cut open. There was a small area of consolidation in the lungs. The other organs were grossly normal. The material from the jejunum and from the duodenum was centrifugated, decanted, filtered and passed through a Berkefeld filter. It was then sterile to culture. No demonstrable toxic effect was produced when these two solutions were injected separately into the peritoneal cavities of white mice in amounts of 0.5, 1 and 1.5 cc. The microscopic sections of the organs showed a moderate degree of central hemorrhagic necrosis of the lobules of the liver and hyperemia of the spleen. The mesenteric lymph glands demonstrated lymphoid hyperplasia. The muscle of the heart was normal. A section through the small area of consolidation showed bronchopneumonia. The kidneys were practically normal, except for an occasional tubular cast. There was some thickening in the muscularis of the obstructed jejunum, but there was

no marked change in the bowel at other points. The immediate cause of death was acute intestinal obstruction with the formation of a closed intestinal loop from intussusception in the ileum. In addition, there was beginning bronchopneumonia.

Dog 492.—First Stage: The dog weighed 14.2 Kg. A lateral anastomosis was performed in the same manner as described for dog 493.

Second Stage: The weight was 15 Kg. Twenty-six days later, a pylorectomy and anterior gastro-enterostomy were performed as described for dog 493.

Third Stage: The weight was 14 Kg. Nineteen days later an obstruction was produced, 48 cm. from the stomach; in addition, the upper part of the jejunum was sectioned as described for dog 493 (fig. 4).

There was no marked change in the behavior of the animal immediately following obstruction. The general condition was excellent even up to the twenty-eighth day, except for gradual loss of weight from 14 to 7 Kg. This was an average loss of 0.24 Kg. or 1.7 per cent per day. The dog was found dead on the morning of the twenty-ninth day. During the period of obstruction, an average

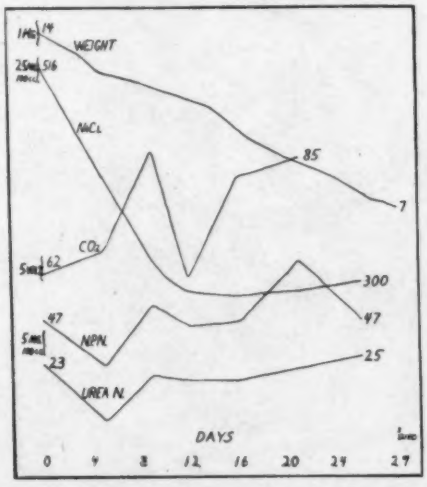

Fig. 8.—Weight and blood chemistry readings for dog 492; obstruction at 48 cm.; death on the twenty-ninth day.

amount of from 300 to 400 cc. of water was taken daily by mouth, to which sodium chloride and sometimes dextrose were added. Meat was eaten about twice a week. Vomiting occurred about every fourth day. The output of urine was from 150 to 250 cc. per day. Small stools were passed about every fifth day. The blood chlorides fell from 516 to 300. The nonprotein and urea nitrogen showed only slight fluctuation up to the twenty-sixth day, on which the last determination was made. There was a rise in carbon dioxide capacity from 62 to 85 (fig. 8). Autopsy revealed only moderate distention of the stomach and obstructed jejunum, which was most pronounced at the distal end, where the diameter was 2.1 cm. The bowel below this was only slightly collapsed (fig. 9). The gallbladder was gray and thickened, and contained golden yellow semisolid material. The mesenteric lymph glands were somewhat enlarged, but were not suppurative. There was pronounced muscular atrophy. The liver, kidneys, spleen, lungs and heart showed no marked gross changes. The microscopic sections revealed central hemorrhagic necrosis of the lobules of the liver which was less marked than in

dog 493. The spleen was slightly hyperplastic. The mesenteric lymph glands demonstrated slight hyperplasia. In the wall of the gallbladder there was diffuse leukocytic infiltration and hyperplasia of the lymphoid elements of the submucosa, compatible with chronic cholecystitis. The pancreas, heart muscle and kidneys were normal. There was a slight amount of hemorrhagic exudate in the alveoli of the lungs. Death was due to the long-standing obstruction and starvation. There is a possibility that chronic cholecystitis was a factor.

Dog 489.—The three stages as desctribed for dog 493 were performed at intervals of three weeks. The weight at the time of the first was 21 Kg., for the second 24.4 Kg. and for the third 21.4 Kg. The obstruction was produced 76 cm.

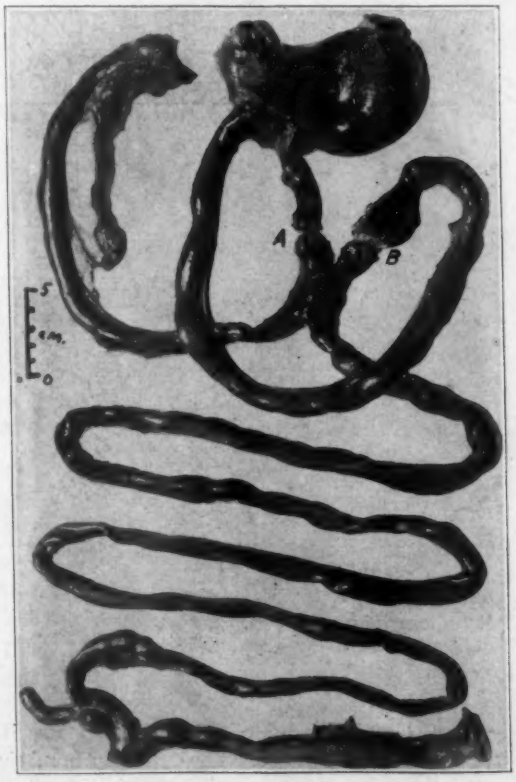

Fig. 9.—Slight distention of stomach and jejunum down to obstruction at *B*, in dog 492. Duodenum and jejunum, interrupted at *B*, emptying into ileum through lateral anastomosis.

from the stomach. The general behavior of the dog was practically normal following the obstruction, its general condition remaining good until after the twenty-ninth day. It then became weak and could not stand or even sit up. It died on the afternoon of the thirty-third day. About 500 cc. of water was taken by mouth daily, to which 1 Gm. of sodium chloride was added every second or third day, and occasionally dextrose or milk. On the average of every third day a small feeding of meat was given, which was eaten with considerable relish. About 300 cc. of urine was voided daily; a trace of albumin was observed during

the last week on two examinations. Vomiting occurred on the average of every third day. Just before death, a liter of thick gray fluid was vomited. Small stools were passed about one or two times a week. The weight declined from 21.4 to 10.9 Kg., practically half of the original weight; the average loss was 0.32 Kg. or 1.48 per cent per day. The blood chemistry showed a fall in chlorides from 528 to 336. The carbon dioxide capacity, after a preliminary drop during the first ten days, rose from 62 to 127. The nonoprotein nitrogen, after a similar preliminary fall during the first week and a half, rose with some fluctuation during the third and fourth week and was high on the last day of life; the total change was from 43 to 320. The urea nitrogen paralleled the nonprotein nitrogen and changed from 21 to 104 (fig. 10). Autopsy revealed distention of the stomach and obstructed jejunum, which was most marked in the distal 9 cm. where it measured 4.5 cm. in diameter. The duodenum was moderately distended, mea-

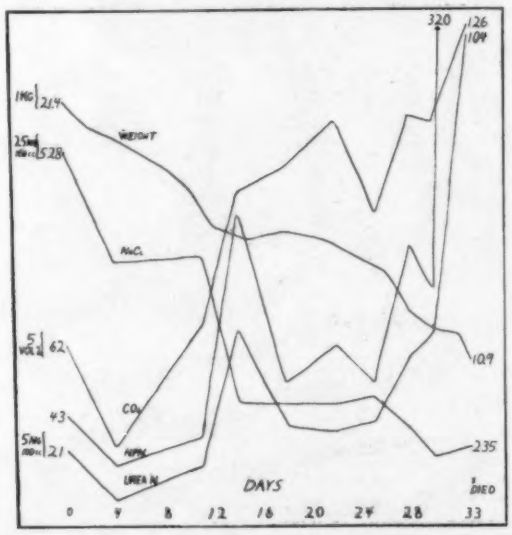

Fig. 10.—Weight and blood chemistry readings for dog 489; obstruction at 75 cm.; death on the thirty-third day.

suring 2 cm. in diameter. The bowel below the entero-anastomosis was collapsed. The stoma of this anastomosis was almost closed, barely admitting the tip of a hemostat. This stenosis had apparently caused a partial obstruction and dilatation of the duodenum (fig. 11). The lungs, heart, kidneys, liver, spleen and pancreas showed no gross changes. Muscular atrophy was marked, and there was practically complete absence of adipose tissue. The mesenteric lymph glands were enlarged and soft but not suppurative. The stoma of the gastro-enterostomy admitted three fingers. There was a small ulcer, about 0.8 cm. in diameter, at the junction of the gastric and jejunal mucosa at the distal end of the stoma. The stomach and jejunum contained thick gray material; the duodenum contained watery brown fluid. The microscopic sections also showed hemorrhagic necrosis in the central portion of the lobules of the liver. The kidneys were apparently normal except for occasional evidence of tubular degeneration. The lungs revealed some hypostatic congestion with recent hemorrhagic exudate. The section of the spleen showed a large number of phagocytic pigment-containing cells. There was

hyperplasia in the section of the lymph gland. The pancreas, gallbladder and muscle of the heart were normal. The obstructed jejunal wall showed some thickening in the muscularis. In the section through the gastrojejunal ulcer, the normal gastric mucosa was present up to the margin of the ulcer where there was a defect, the floor of which was made up of granulation tissue. Normal jejunal mucosa was present on the other side of the defect. Sections of the rest of the bowel were normal. Death was due to the long-standing obstruction and starvation without any evidence of complication other than a small gastrojejunal ulcer which probably did not hasten the time of death.

TECHNIC

Morphine-ether anesthesia and aseptic technic were used throughout. The end-to-side and lateral anastomoses were made with two rows of sutures. The

Fig. 11.—Marked distention of stomach and jejunum down to obstruction at *B* in dog 489; moderate distention of duodenum and jejunum down to *A*, where it was interrupted; collapse of bowel below obstruction and the lateral anastomosis.

bowel was interrupted by clamping, doubly ligating, cutting between the ligatures and then invaginating the stumps with purse-string sutures. In the last four dogs, side-to-side anastomoses were used entirely; the results were better, as there was less danger from leaks. Whenever the bowel was interrupted in these last four dogs, the invaginated ends were approximated by tying the two purse-string sutures together. This not only prevented intussusception of the distal part of the bowel, which otherwise occurred frequently, but also diminished the chance for the proximal part to blow out when the bowel became distended. Because of the high operative mortality in the two-stage procedure, the three-stage was adopted. This gave far better results. In a small series in which the obstruction and the anastomoses were performed at one time, the mortality rate was 100 per cent. There was a marked tendency to loss of weight following the preliminary operations, and it was often impossible to overcome it even by forced feeding with hamburger and milk. This was especially true if the

secretions emptied into the lower ileum; and was even more likely if the secretions did not have an opportunity to flow through the upper segment of jejunum as in the first three dogs. The factor which appeared to influence the results most favorably was the bringing of the weight up to normal or better before proceeding with the next stage. Dog 337 was the only one of a series of eight that survived the first stage. In a series of eighteen animals operated on like dog 515, eight survived the first stage and when obstruction was performed, six died before the sixth day from a complication; however, one lived for thirteen days with a low obstruction near the cecum. In two dogs of the series of five which survived the second stage as described for dog 983, chronic jejunal ulcer developed. In one it occurred opposite the stoma, which perforated and caused general peritonitis and death. In the other animal, three ulcers were found in the jejunum just beyond the gastro-enterostomy. The best results were obtained by the three-stage procedure as described for dogs 493, 492 and 489, these representing a third of the dogs used in this series. Concerning the blood chemistry, the plasma carbon dioxide capacity or combining power was determined in volumes per hundred cubic centimeters by the van Slyke method. The total whole blood chlorides were estimated as sodium chloride by Whitehorn's modification of Volhard's technic. The nonprotein and urea nitrogen determinations were made by Koch and McMeekin's method.

COMMENT

Although the average length of life of dogs in which high intestinal obstruction has been produced is from two to eight days, according to Haden and Orr,[8] it has been prolonged by several methods. The short-circuiting procedure described in this paper has resulted in prolonging it more than a month. Eisberg and Draper,[9] in a brief report of short-circuiting operations similar to that described for dog 337, stated that animals lived as long as seventeen days. When from 1 to 2 per cent sodium chloride solution is injected subcutaneously or intravenously daily into dogs with simple high obstruction, they live from three to four weeks.[10] Similarly, two dogs into which sodium chloride solution was injected in the same manner for the first five days, followed by a period of starvation, lived for twenty-one and twenty-eight days, respectively.[11] If the pancreatic ducts are ligated[12] and obstruction is then produced, dogs will live somewhat longer than the average, but life is not strikingly prolonged.

There is no clear explanation for the increased length of life of dogs with the biliary, pancreatic and duodenal secretions short-circuited

9. Eisberg and Draper: Intestinal Obstruction, J. A. M. A. **71**:1634 (Nov. 16) 1918.

10. Haden and Orr (footnote 8). Hartwell; Hoguet, and Bickman: An Experimental Study of Intestinal Obstruction, Arch. Int. Med. **13**:70 (May) 1914.

11. Foster, W. C., and Hausler, R. W.: Acute Intestinal Obstruction: Simple Obstruction, Arch. Int. Med. **36**:31 (July) 1925.

12. Sweet; Peet, and Hendrix: Ann. Surg. **63**:720, 1916. Eisberg: Ann. Surg. **74**:584, 1921.

below the point of obstruction of the bowel. If it is assumed that the cause of death in obstruction is a toxin, it would seem that these three secretions or one or a combination of any two must be responsible for the elaboration of the toxin in the obstructed bowel, because short-circuiting them below the obstruction prevents the rapid occurrence of death that ordinarily ensues. It is difficult to decide which of the secretions might be responsible for the formation of toxin. The bile has been separately excluded from the obstructed portion of the bowel without any appreciable effect on the length of life by Eisberg,[13] Draper [14] and others. The pancreatic secretion has been considered by Eisberg,[13] Sweet,[15] Draper and Maury,[16] Sweet, Peet and Hendrix [12] and others as the important factor in the formation of the toxin. The duodenal secretion has been held to be the source of the toxic agent by Whipple, Stone, and Bernheim,[1] Bunting and Jones,[17] and others.

Aside from the theory of the formation of toxin in the obstructed bowel another factor that must be considered is the loss of digestive secretions. In dogs approximately 500 or 600 cc. of bile, a like amount of pancreatic juice and about 100 cc. of duodenal secretion are poured into the upper end of the jejunum daily. When this amount of fluid empties into a short, obstructed loop of jejunum, it could hardly be expected to be absorbed daily. Its loss through vomiting without replacement would certainly produce a serious disturbance in the water balance of the body. These secretions are rich in minerals, and the loss of this amount of mineral matter without replacement would also be injurious to the mineral balance of the body, especially because of the loss of sodium and of chloride ions.[6] Although a biliary fistula or a duodenal fistula from which the bile and pancreatic juice have been excluded are compatible with life, a pancreatic fistula causes death in a few days.[18] In this experiment, in which all three secretions empty into the bowel below the obstruction, the prolongation of life for a month or more might well be explained on the basis of the prevention of a marked disturbance of the water and mineral balance of the body by resorption of these three secretions in the lower bowel. However, a point against this being an important factor is that death occurs in two or three days in pyloric obstruction despite the fact that the secretions poured into the duodenum are below the point of obstruction. In this case the gastric secretion is lost. In the

13. Eisberg (footnote 12, second reference).

14. Draper: Am. J. M. Sc. **137**:725, 1909.

15. Sweet: Penn. M. J. **16**:520, 1912-1913.

16. Draper, J. W., and Maury: Death in Acute Intestinal Obstruction and Kindred Conditions Due to Physiologic Disturbance, J. A. M. A. **54**:5 (Jan. 1) 1910.

17. Bunting and Jones: J. Exper. Med. **17**:192, 1913.

18. Elman and McCaughan: J. Exper. Med. **45**:561, 1927.

experiment with the three secretions short-circuited below the high obstruction, there is a short segment of jejunum connected with the stomach from which there might be absorption of gastric secretion to some extent or in which changes might take place which alter the picture from that produced by pyloric obstruction.

The clinical application of the results of this experiment depends on the interpretation which is made. If it is assumed that a toxin is formed in the obstructed portion of the bowel, this would favor the use of jejunostomy at the time that an acute obstruction is relieved surgically to aid in the elimination of the stagnated toxic material as well as to lessen the distention believed to influence the absorption of the toxin. On the other hand, if it is assumed that death is due to a failure of resorption of the three normal digestive secretions, a jejunostomy at the time of operation for obstruction would be contraindicated, because it would drain off material which would be of more value to the body if resorbed. An exception to this would be when the distention of the obstructed bowel was of such a degree that there was danger of perforation unless a jejunostomy was performed. Instead, the administration of large amounts of 0.9 per cent of sodium chloride solution subcutaneously or intravenously would be indicated to replace immediately the water and minerals which had been lost by failure of resorption.

SUMMARY AND CONCLUSIONS

1. When [19] high obstruction was produced in six dogs, in which the biliary, pancreatic and duodenal secretions had been short-circuited into the bowel below the point of obstruction, they lived from twelve to thirty-three days.

2. The general behavior of these dogs was not markedly changed following the obstruction until a few days before death. They drank from 300 to 500 cc. of water a day, ate meat occasionally, vomited about twice a week, averaged an output of from 200 to 300 cc. of urine a day, and passed small black or brown stools about twice a week.

3. The weight of these dogs gradually declined as much as one-half in those which lived the longest; the average loss was 0.3 Kg. or 1.73 per cent per day.

4. The blood chemistry showed a gradual fall in chlorides and a gradual rise in the plasma carbon dioxide capacity. The nonprotein and urea nitrogen often showed a slight preliminary fall during the first ten or twelve days, followed by a gradual rise, which became marked just before death.

5. Autopsy revealed distention of the stomach and the obstructed portion of the jejunum, which was most noticeable just above the point

19. Jenkins: Proc. Soc. Exper. Biol. & Med. **26**:464, 1929.

of obstruction. The microscopic sections of the organs did not demonstrate any marked changes, with the exception of the liver in which there was central hemorrhagic necrosis of the lobules. Death was due to complications in most of the dogs, although the two which lived the longest died from no determinable cause other than the long-standing obstruction and starvation.

6. The explanation for this marked prolongation of life when these three secretions are short-circuited is not clear. Either these secretions are responsible for the formation of a toxin in the obstructed bowel which was prevented in this experiment, or, when resorbed in the lower bowel, they prolong life by preventing a marked upset in the water and mineral balance of the body, which is thought to be the case when they fail to be resorbed.

LOCALIZATION OF BACTERIA IN TISSUES OF LOWERED RESISTANCE*

W. WARREN SAGER, M.D.
Fellow in Surgery
AND
ALLEN C. NICKEL, M.D.
ROCHESTER, MINN.

The secondary infection of a so-called sterile abscess, by the intravenous injection of streptococci, is an outgrowth of work on post-operative wound infection in which we are engaged. We are attempting to arrive at a method by which the incidence of such infections can be reduced. As part of this work we induced infection with a known number of bacteria in a surgical wound in a dog, and then irrigated the wound with various antiseptic and germicidal solutions. We observed that an ordinary wound would heal, after contamination with a certain number of bacteria, without gross evidence of infection, such as oozing of pus, pus pockets, prolonged induration or sloughing of tissue. We also noted that certain wounds copiously irrigated with antiseptic solutions, would become infected even though the number of bacteria in each wound was less than that which a wound would usually dispose of without becoming grossly infected. In view of these facts we felt that another factor was involved; namely, that the traumatized or injured tissue of surgical wounds, because of its lowered resistance, might attract micro-organisms that were circulating in the blood.

Hematogenous infection of wounds is recognized clinically, yet scientific proof of its occurrence is infrequent. Findlay,[1] however, gives an excellent résumé of publications referring to this subject. He believes that histamine-like substances liberated in the traumatized places are the specific agents which cause organisms present in the blood stream to localize in these places.

Frank,[2] in reporting rare complications following scarlet fever, mentioned two children, aged 5 and 6 years, respectively, each of whom received 25 cc. of scarlet fever immune serum in the gluteal muscles on the second day of the disease. The temperature dropped to normal by the next day. In each case, on the fourth day of the illness, the

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* From the Division of Experimental Bacteriology, The Mayo Foundation.

1. Findlay, G. Marshall: Histamine and Infection, J. Path. & Bact. **31**:633, 1928.

2. Frank, Heinz: Klinische und bakteriologische Beobachtungen an einigen selternen Scharlachkomplikationen, Deutsches Arch. f. klin. Med. **160**:159, 1928.

temperature rose again, and there was tenderness at the site of the injection of the serum. Four days later, at the site of these injections there developed an abscess from which hemolytic streptococci were isolated in pure culture. The author concluded that either the streptococci were present in the tissues before the injection of the serum or they entered afterward.

Since surgical asepsis is only relative, we felt that the easiest and surest way to obtain traumatized, yet sterile, tissue was through the production of a sterile abscess. We tried various methods. Boiling water sometimes produced an abscess, yet the results were not uniform. Different strengths of aqueous solution of silver nitrate were tried. Weak solutions produced only superficial necrosis of the skin. A 10 per cent solution, however, caused localized edema, with resultant necrosis of the overlying and underlying tissues, and the picture was fairly constant. Definite caseation and purulent secretion did not result in these places, yet a serous fluid could be aspirated from them for culture. It was essential that silver nitrate should not get into the peritoneal cavity, for every rabbit in which this inadvertently happened died. Consequently, we did not attempt intramuscular injection, but made all injections subcutaneously.

METHOD

Rabbits were used exclusively, and the following procedure was adopted: After the hair had been removed from the abdomen and lower part of the chest of a rabbit, blood was aspirated from the heart, and cultures made from it were sterile. Two abscesses were then made on the abdomen by a subcutaneous injection of from 1.5 to 2 cc. of a 10 per cent aqueous solution of silver nitrate for each abscess. Six to ten hours later, except in the control rabbits, green-producing streptococci were injected intravenously. The strains of bacteria used were three strains of green-producing streptococci. Each of these strains had been obtained from the gallbladder of rabbits which had been given intravenous injections of streptococci that had been obtained on culture from surgically resected gallbladders in clinical cases. We used such strains because they are not the common contaminants in work with rabbits, and especially because they had shown elective localizing power which, if inherent long enough, might be used later for identification purposes. The dosage employed varied from 5 to 7 cc. and was that usually employed in animal tests.

RESULTS

Usually, within twenty-four hours after the injection, blood cultures were again sterile. Four or five days after injection, the sites where silver nitrate had been injected were raised and edematous. Fluid was aspirated from these places.

We had two sets of controls. In the first row of the table are listed six rabbits, blood cultures from which originally were sterile. Silver nitrate was then injected, and fluid, aspirated from the abscesses four or five days later, did not produce growth in culture. The five rabbits in the second row were treated similarly, and cultures made from fluid from the abscesses in all five also were sterile. After we had proved that cultures from these abscesses were sterile, we injected streptococci intravenously. Even then, the blood of these rabbits became sterile; nevertheless, we were able to isolate the streptococcus from the abscesses of two of the five rabbits. Perhaps the reason for our failure to isolate the streptococcus from the abscesses in the three other rabbits was because of the fact that the processes of healing were rather far along by the time we made the cultures. Therefore, possibly the injected bacteria were unable to penetrate the tissue to enter the

TABLE.—*Experimental Infection of Sterile Abscesses by the Intravenous Injection of Streptococci Isolated from a Gallbladder Removed at Operation*

Number of Rabbits	Bacteria Injected	Culture		Bacteria Injected	Culture		Necropsy Data		
		Blood	Abscess		Blood	Abscess	Blood	Gall-bladder	Other Organs
6	..	000 000	000 000	..	..	..	0000	0000	0000
5	..	000 00	000 00	5	000 00	++	000	000	000
7	7	0000 000	++++ +++	..	..	..	0000 000	++++	0000 000
2	*	..	..	..	..	..	00	++	00

* Culture of abscess.

abscesses. In the third row are listed seven rabbits which at the beginning of the experiment gave negative blood cultures. They then received injections of silver nitrate and, six to ten hours afterward, received an intravenous injection of green-producing streptococci. After four or five days, a green-producing streptococcus was recovered from the abscesses of all seven rabbits, whereas the blood cultures of all were negative. At necropsy, a green-producing streptococcus was recovered from the contents of the gallbladders of four of the seven rabbits that received injections. In two of these four rabbits there were also gross lesions of the wall of the gallbladder. In the third rabbit, the bile was pale brown-green and thin, whereas in the fourth rabbit, the gallbladder and bile were grossly unchanged. Cultures from other organs were all sterile, and there were no other gross lesions. In order to determine further whether the strain isolated from the abscess was the same as that originally injected, the streptococcus obtained from an abscess was injected into two rabbits. In the last line of the table it is shown that

at necropsy the streptococcus which had been isolated from the abscess, localized in and was recovered from the gallbladders of both rabbits when injected intravenously; all other cultures, however, were negative.

COMMENT

Since silver nitrate in a dilution of 1:1,000 is itself a germicide and prevents growth of the green-producing streptococcus in ordinary broth culture, and since we were able to isolate this streptococcus so constantly from the originally sterile abscesses but never from the control abscesses, we believe that the strains so isolated were not contaminants. Because the strains also became localized in the gallbladders of some of the rabbits and because even those strains that were recovered from abscesses tended to become localized in the gallbladder, we feel that the strain isolated from the abscess was the same strain that originally was introduced intravenously. These results suggest that bacteria tend to become localized in traumatized or injured tissues, such as may be produced easily by surgical operations. They raise the question whether a postoperative wound infection might not sometimes be of hematogenous origin in the course of transient bacteremia. They also show that bacteria may become localized in places of lowered resistance but that they also may possess selective action. In these instances, the bacteria selected the gallbladder, the region where they originally had been obtained, and this indicates that the elective localizing power of microbes, as advocated by Rosenow, is a reality.

SUMMARY AND CONCLUSIONS

1. In rabbits which originally gave negative blood cultures, abscesses made by the subcutaneous injection of silver nitrate remained sterile.

2. A number of such abscesses became infected secondarily after the intravenous injection of bacteria.

3. The organism isolated from the abscess resembled the organism originally introduced intravenously and had the same elective localizing power.

4. These results may explain why some clean surgical wounds become infected.

A REVIEW OF UROLOGIC SURGERY

ALBERT J. SCHOLL, M.D.
LOS ANGELES
E. STARR JUDD, M.D.
ROCHESTER, MINN.
LINWOOD D. KEYSER, M.D.
ROANOKE, VA.
GORDON S. FOULDS, M.D.
TORONTO, CANADA
JEAN VERBRUGGE, M.D.
ANTWERP, BELGIUM
AND
ADOLPH A. KUTZMANN, M.D.
LOS ANGELES

(Continued from p. 942)

BLADDER

Tumor.—Bumpus,[35] in a study of records of cases of tumor of the bladder observed in the Mayo Clinic, attempted to estimate the benefit which may be expected from the various forms of treatment.

If the base of the tumor cannot be seen, it is not safe to judge the operability of the growth from its size, since growths that occupy the entire cavity of the bladder frequently have pedicles not more than 1 or 2 cm. in diameter. It is the custom in the clinic to explore suprapubically in all cases of tumor of the bladder in which the general condition of the patient allows surgical treatment. Of 465 suprapubic explorations of tumors of the bladder, it was possible to institute some form of treatment in all but sixty-six. Even without treatment, suprapubic drainage afforded much relief by diminishing spasm and reducing secondary infection to a minimum.

Not until the degree of malignancy has been determined can appropriate treatment be advised. If the tumor is comparatively small and the degree of malignancy graded 1 or 2, its destruction by fulguration through the cystoscope is advisable. The chief complication in these comparatively benign growths is recurrence; Crenshaw estimated that there is recurrence in approximately one third of such cases.

Diathermy is preferable to resection because of the slight deformity which results. Resection of a growth sometimes destroys the spherical contour of the bladder; there is a tendency to hour-glass deformity,

35. Bumpus, H. C.: The Present Methods and Results of Treating Tumors of the Bladder, J. Urol. **21**:371, 1929.

making it difficult for the bladder to empty satisfactorily, and residual infection occurs. Successful diathermy leaves only a scar at the site of the tumor, usually broad and not cordlike as after resection.

Radium was used extensively for several years at the Mayo Clinic in the treatment of tumors of the bladder. In some cases it was applied prior to operation through the cystoscope with the idea of irradiating the tumor so that any malignant cells left in the tissue would be incapable of reproduction. This method was not successful, since the edema following irradiation made it difficult to determine the exact extent of the tumor. In forty-six cases radium was used, sometimes in conjunction with other surgical procedures. In fifteen cases the bladder was opened and radium emanation seeds were inserted into the growth, 1 cm. apart. In twelve cases which were traced the average length of life after operation was six months.

Diathermy was used in treating tumors of the bladder which were situated in such a way or were so extensive that resection or excision was not possible. If the growth was pedunculated, it was partially removed by excision and the remainder was removed by electrocoagulation. The length of convalescence has been observed to be in direct proportion to the extent of the growth. In twenty-nine cases in which diathermy has been used for the destruction of tumors in which malignancy was graded 3 or 4, sixteen of the patients are living and four are in the third year after treatment without recurrence and in good health. Of 179 patients with tumors of the bladder of the same degree of malignancy, treated by various surgical measures, fifty are living, twenty-seven more than three years. This comparison indicates that diathermy, instead of replacing strictly surgical measures, has brought cases formerly thought to be hopeless within the scope of successful treatment.

[COMPILERS' NOTE.—Initial determination of the degree of malignancy and the size and site of the tumor, cystoscopic fulguration of small tumors graded 1 and 2, resection of small tumors when resection is not attended by marked subsequent deformity, partial resection combined with diathermy, or diathermy alone, in the more extensive tumors of higher degrees of malignancy, and a strong trend away from treatment by radium would seem to epitomize the present views of this writer.

The report gives the impression that electrocoagulation finds a wide field for application in this branch of urology, which has been so disappointing. The classification of tumors of the bladder is as yet much confused and the casual reader of urologic literature is often at a loss to correlate reports from different clinics in which a large number of patients are observed. Frontz and Barringer recently presented criteria for the treatment of tumors of the bladder by radium and

resection which are possibly somewhat at variance with the principles set forth by Bumpus in his report. The grading of epithelial neoplasms, although fairly exact in the hands of Broders and his co-workers, offers a wide opportunity for error in interpretation when applied by pathologists in general, due to the personal equation in determining degrees of cellular differentiation. Nevertheless, Bumpus has shown that electrocoagulation methods, alone or combined with resection, are likely to contend strongly for precedence over radiotherapeutic procedures in the treatment of vesical neoplasms in the immediate future.]

Wilensky and Firestone [36] reported a case of spontaneous disappearance of a papillary carcinoma of the bladder in a man, aged 63 years. The patient had mild diabetes and tabes dorsalis. General examination revealed that the pupils were unequal and irregular and did not react to light or in accommodation. Reflexes at the knee were absent. The Wassermann reaction was positive, ++++. Cystoscopic examination showed a papillary tumor with a broad base about 1 cm. in diameter, on the posterior wall midway between the ureteral orifices, and just above the trigone. Pathologic examination of small specimens from the growth showed papillary carcinoma. Eight days after cystoscopic examination, a suprapubic incision in the median line was made, the bladder was opened, and its interior was exposed to full view. The entire bladder could be thoroughly and completely explored and palpated. A tumor was not present; the site from which the specimen had been taken at biopsy could not be distinguished in any way from the remainder of the mucosa. The interior of the bladder was apparently normal. The bladder and abdominal wall were closed, and a suprapubic tube was left in for drainage. The patient died thirty-eight days afterward. Necropsy showed suppuration of the prevesical space and abdominal wall, with subacute cystitis and ascending pyelitis of the right kidney. The bladder did not show evidence of malignant growth.

Kretschmer and Barber [37] reported a case of carcinoma in a diverticulum of the bladder, a condition which they have observed rarely. They stated that a diverticulum may be the seat of changes that are in line with other pathologic changes which occur in the bladder, such as infection, stone, tumor and leukoplakia. Cases are generally not recognized until late in the course of the disease because patients delay in consulting physicians. The prognosis has been extremely bad in the past, and surgical results have been only mediocre.

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36. Wilensky, A. O., and Firestone, Abraham: Spontaneous Disappearance of Papillary Carcinoma of the Bladder, J. Urol. **21**:611, 1929.

37. Kretschmer, H. L., and Barber, K. E.: Carcinoma in a Bladder Diverticulum: Report of a Case and a Review of the Literature, J. Urol. **21**:381, 1929.

Hunt [38] stated that it is not common to find primary malignant disease in a diverticulum without involvement of the bladder. He reported five cases in which the primary epithelioma was confined to a diverticulum; four of the patients he operated on.

A man, aged 62 years, was operated on by Judd. At operation a papillary epithelioma was found almost to fill a diverticulum and to protrude through the opening of the diverticulum into the bladder, but the diverticulum alone was affected. The mucosa of the bladder was free. The diverticulum was entirely excised. Six months later symptoms of recurrence in the bladder were manifest. The patient died a year after the operation.

In the second case, the patient, a man, aged 59 years, had a large, soft cystic mass, which filled the lower half of the abdomen. He died following cystostomy. At necropsy a large diverticulum was found emptying into the right wall of the bladder. In its contracted state the diverticulum was as large as the bladder; if one is to judge from the size of the abdominal mass and the cystographic data, the diverticulum must have been at least twice the size of the bladder previous to drainage. It was relatively thin-walled, and its walls did not contain muscle fibers. A large foramen about 2 cm. in diameter communicated between the diverticulum and the bladder. The right ureter, which was double, united at the bladder, entered the diverticulum, and a true interureteral bar extended from one ureteral orifice in the diverticulum, through the foramen of communication, to the left ureteral orifice in the bladder. The wall of the bladder was greatly hypertrophied. In the lateral wall of the diverticulum, below the right ureteral orifice, were two flat, malignant-appearing lesions, one about 2 cm. and the other about 1 cm. in diameter, which, on microscopic examination, proved to be squamous cell epithelioma.

The third case was that of a man, aged 55 years, in whom extravesical excision of a diverticulum of the right base and transvesical excision of the left diverticulum were performed. The diverticulum on the right side was densely adherent and because the right ureter emptied into the bladder at the orifice of the diverticulum, it was divided and subsequently reimplanted into the bladder. The diverticulum on the right was about 4 cm. in diameter and contained a primary malignant papilloma 2 cm. in diameter, graded 2, entirely confined within the diverticulum.

The fourth case was that of a man, aged 70 years, in whom suprapubic drainage of the diverticulum and bladder was instituted and maintained for about a month, when extravesical excision of the diver-

38. Hunt, V. C.: Malignant Disease in Diverticula of the Bladder, J. Urol. **21**:1, 1929.

ticulum was carried out. The capacity of the diverticulum was about 1 liter. On removal of the diverticulum a squamous cell epithelioma 3 by 2 by 1.5 cm., graded 4, was found in its lateral wall away from the orifice of communication between the diverticulum and bladder and confined entirely to the diverticulum. Convalescence was satisfactory until the fifteenth day, when an attack of pulmonary embolism occurred, causing death twenty days after operation.

The fifth case occurred in a man, aged 55 years. The bladder was explored under sacral anesthesia and block of the abdominal wall. The wall was greatly thickened, and there was extensive trabeculation. In the left lateral wall, above the ureteral orifice, an opening about 1.5 cm. in diameter led into a diverticulum with capacity larger than that of the bladder. There were two additional diverticula of the base of the bladder with their openings just lateral to the ureteral orifices. These diverticula were of about equal size and were about 7.5 cm. in diameter. The prostate gland was slightly enlarged intravesically and a moderate degree of cystitis was present. Extravesical excision of the large diverticulum of the left lateral wall was readily accomplished. The diverticulum was 12.5 cm. in diameter. Examination disclosed a sessile tumor about 1 cm. in diameter situated well out in the lateral wall of the diverticulum. Microscopic examination revealed an epithelioma graded 3. Transvesical excision of the diverticulum of the left base of the bladder by the Geraghty method was made.

Stones in Children.—Belacesco [39] stated that stones in the bladder of children are common in Roumania. During a period of fifteen years he performed suprapubic cystostomy in seventy-six cases; stones from 1 mm. to 2 cm. in diameter were removed. The age varied from 15 months to 3 years in twenty-one cases; in twenty-five cases it was between 3 and 6 years, in fourteen cases between 6 and 9 years, and in sixteen cases, between 9 and 18 years. All the patients were boys except one, a girl, aged 3 years. In seventy of the seventy-six cases the cystostomy orifice was closed at operation; postoperative complications or long-standing fistula did not occur. In the remaining six cases, it was necessary to institute drainage, because the patient was in a generally precarious state as a result of ascending infection. Four of these patients died.

The main symptoms were incontinence, day and night, pain, sudden interruption in urination, and only rarely hematuria. A diagnosis was made in each instance by simple fluoroscopy. Balacesco stated that risk does not accompany primary suture of the bladder.

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39. Balacesco: Soixante-seize cas de calculs vésicaux de l'enfant, Bull. et mém. Soc. nat. de chir. **15**:322, 1929.

Paralysis.—Boyd and Bailey [40] stated that varying opinions exist among urologists as to the best method of handling retention of urine which occurs in cases of acute paralysis of the bladder. Some urologists advocate attempting to empty the bladder by massage of the prostate gland and pressure on the abdomen without catheterization. Other urologists advocate intermittent catheterization; a few advocate indwelling catheters, and a few, suprapubic drainage. Boyd and Bailey stated the belief that suprapubic cystotomy is the procedure of choice in almost all of these cases.

Usually in cases of injury to the spinal cord, complete paralysis of the detrusor urinae muscles and active contraction of the internal sphincter occur at once. Urine accumulates in the bladder, the bladder distends to an enormous size, and in forty-eight hours there is usually an overflow incontinence of urine. If conditions are favorable, this gives way in four or five weeks to automatic urination. Before this the bladder will gradually begin to discharge at irregular intervals more and more of the content, as the result of which capacity of the organ is reduced slowly. If so-called automatic urination develops, a large quantity of urine is expelled at each micturition.

Experience has shown that continuous drainage offered by suprapubic cystotomy is superior to intermittent catheterization in the treatment of patients with paralyzed bladders. Catheterization is thus avoided.

Eight cases of paralysis of the bladder were considered. In the first two cases operation was not performed. In the third case, in which paralysis was caused by infection of the spinal cord, suprapubic drainage relieved symptoms in the bladder. The fourth case was one of traumatic fracture of the spine. Drainage was established on account of severe infection. In the fifth and sixth cases the return of function was sufficient to permit removal of the suprapubic tube. In the two remaining cases the patients were paralyzed for life by traumatic accidents. Infection of the bladder developed after catheterization. The patients were in good health except for paralysis, one patient, twelve months, and the other nine months, after suprapubic drainage.

Priestley [41] stated that vesical paralysis is more likely to be caused by malignant tumors in the spinal cord than by benign tumors. Tumors in the cervical region, benign or malignant, cause vesical paralysis less frequently than tumors in any other situation. Malignant tumors cause paralysis of the bladder earlier after the appearance of the first neurologic sign than do benign tumors. Symptoms in the bladder may

40. Boyd, M. L., and Bailey, M. K.: Suprapubic Cystotomy in Bladder Paralysis, J. Urol. **21**:623, 1929.

41. Priestley, J. T.: The Spinal Cord Bladder, J. Urol. **21**:635, 1929.

be expected about six months after the first symptom in the cord, but there are wide variations in this time relationship. The usual symptoms in the bladder resulting from a tumor in the spinal cord are difficulty of urination, retention and incontinence of overflow. In cases of trauma to the spinal cord, retention is present from the start.

The treatment of choice for retention due to lesions of the cord is noncatheterization and the development, if possible, of normal function of the bladder. If this fails, emptying of the bladder by suprapubic pressure is preferable to catheterization. In some cases suprapubic cystotomy is necessary. Priestley considered that the most important factors in the development of normal function of the bladder are noncatheterization, the utilization of mass reflex action, the systematic use of suprapubic pressure and the presence of a noninfected bladder.

[COMPILERS' NOTE.—Infection in a paralyzed bladder is a condition which every urologist approaches with apprehension. If there is retention, the easiest way is often chosen by the attending physician who catheterizes the patient before a urologic consultant is called. Priestley emphasized that if infection is to be avoided and the development of autonomic emptying is to be achieved, the catheter is to be held in abeyance even at the expense of cystotomy. Urologists and neurologic surgeons of the present day seem generally to concur in this opinion.]

Fistula.—Legueu [42] used the following method of transperitoneal closure in twenty-four cases of vesicovaginal fistula, with entirely satisfactory results. The patient is placed in an extreme Trendelenburg position, the abdomen is opened, and a self-retaining retractor is inserted. The peritoneal fold, which is reflected from the posterior wall of the bladder across the vaginal vault, is then exposed and brought into view. An incision is next made in the median line through the posterior wall of the bladder and vault of the vagina so as to expose the fistulous openings. The vagina and bladder are separated by means of sharp dissection until the fistulous openings are completely isolated. The bladder is mobilized on all sides at a distance from the fistula. The openings in the bladder and vagina are closed with interrupted catgut sutures. The peritoneal edges are approximated with fine chromic catgut and the incision through the abdominal parietes are closed in the usual manner.

In the postoperative treatment of vesicovaginal fistula, overdistention of the bladder should be prevented by the introduction of a permanent catheter into the bladder or by catheterization every four hours.

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42. Legueu, Felix: The Transperitoneal Closure of Vesicovaginal Fistulae, Surg. Gynec. Obst. **48**:796, 1929.

[COMPILERS' NOTE.—The suprapubic approach, alone or combined with the vaginal route, for the treatment of vesicovaginal fistula seems to be growing in popularity. Young described a transvesical suprapubic operation in 1927. His closure of the fistula was accomplished entirely from the intravesical site. In the same year Roeder described a vaginal operation. He closed the fistula by dissecting free large vaginal flaps which were sutured together, the first suture line being inverted toward the bladder and this inversion being maintained by drawing the suture ends up through a cystotomy opening. Apparently Legueu attacked the fistula extravesically but from within the abdomen, which is somewhat of a departure from the usual technic.]

PROSTATE GLAND

Hypertrophy.—Randall [43] commented on two different types of prostatic enlargement called "middle lobe." Anatomically there are two different glandular elements situated in the median line posteriorly, the posterior commissural glandular tissue, and the subcervical glandular tissue of Albarran. Either may undergo hypertrophy independently of the other or independently of growth of the lateral lobe. Likewise, either may undergo hypertrophy in conjunction with enlargement of the lateral lobe or in conjunction with one another. When the posterior commissural glandular tissue hypertrophies, it first causes thickening and elevation of the posterior vesical lip. On further hypertrophy the commissural tissue raises upward the apex of the trigone, the vesical lip, and the first portion of the floor of the urethra. The sphincter gradually drifts backward and behind the hypertrophying mass, and the hypertrophy is constantly confined by the prostatic capsule and always under the trigonal muscle. It ultimately grows to form a flat, thumblike projection in the cavity of the bladder, with widely separated clefts in the posterolateral angles. In cases of long standing, hypertrophy of the lateral lobes becomes evident. Hypertrophy of the subcervical gland starts as a small, rounded nodule just infrasphincteric and quickly becomes spheroidal. When it is large enough to push up through the sphincter, pedunculation has started, after which this characteristic is never lost or absent. Its only covering is the mucous membrane and its only attachment is its own ducts which form a definite pedicle.

A differential diagnosis may be made by combined rectal and cystoscopic study. On rectal examination, the posterior commissural hypertrophy presents a flattening out of the median prostatic groove with a broad flaring out of the upper lateral limits of the lobe and

43. Randall, Alexander: Genesis, Morphology, and Surgery of Prostatic Middle Lobe Hypertrophy, Ann. Surg. **88**:112, 1928.

a greater mass of tissue in the intervesicular, subtrigonal region. Cystoscopic examination reveals generalized thickening of the posterior vesical lip, partial or complete obscuring of the trigone, and, with retraction of the instrument, a long distance is covered before the posterior urethra is entered. With an instrument in the urethra and a finger in the rectum, the thickened mass is readily felt, as the instrument easily remains in the median line and rides over the hypertrophic lobe. Subcervical hypertrophy of the gland, because of its pedunculated character, presents easily recognized variations. The growth is intravesical; rectal examination is usually unsatisfactory and misleading. If the cystoscope is passed it invariably enters to one side or the other of the lobe, which may be mistaken for the rotundity of enlargement of the lateral lobe.

The enucleation, starting intra-urethrally, includes about one lateral lobe and should pass across the urethra and the apex of the trigone. Then the finger goes directly around the opposite lateral lobe, and the prostatic mass is removed in one piece. In hypertrophy of the subcervical gland, its mucous membrane should not be saved but should be pinched off at once. Randall usually placed a clamp on the lobe, simply twisting its pedicle to the point of rupture. If hypertrophy of the lateral lobe also is present, the suprapubic enucleation entails the removal of the subcervical lobe, and the enculeation of one lateral lobe, and the removal of the other lateral lobe.

In perineal prostatectomy, subcervical hypertrophy presents a peculiar complication, since it does not lie within the prostatic capsule. Because the prostatic capsule is approached on its posterior surface, a complete lateral lobe and commissural growth may be removed, and hypertrophy of the subcervical lobe may be missed entirely. If clean enucleation has been performed on the lateral lobes, a subcervical lobe should be removed as follows: the prostatic tractor is withdrawn entirely, and with a spoon retractor or lobe forceps, entered through the urethrotomy incision, the lobe is grasped and an attempt is made to draw it down through the posterior urethra to a point at which its attachment may be ruptured and the mass may be removed. Because of such difficulties with hypertrophy of the subcervical gland, Randall stated the belief that this type of enlargement belongs essentially to the suprapubic type of operation.

[COMPILERS' NOTE.—This differentiation of two types of median-lobe hypertrophy is often disregarded, especially by those who practice suprapubic operative technic and who clean out the intracapsular tissue from above. Although the subcervical gland type is not intracapsular, it will undoubtedly be removed when the intracapsular enucleation is done. In perineal prostatectomy it is possible entirely to escape the

removal of the nodular subcervical gland unless the precautions outlined by Randall are observed.]

Deaver [44] described his technic for closure of the prostatic bed in suprapubic prostatectomy. He does not use either the prostatic bag or gauze packing. The wound in the bladder is retracted laterally and fore and aft, with the use of the proper-sized Deaver retractors. A small, moist gauze pad is introduced into the fundus of the bladder, over which the upper retractor is placed, so that when traction is made the floor of the bladder will be level. This gives a good view of the wall of the bladder, the prostate gland, the ureteral orifices, and, after removal of the prostate gland, the prostatic bed. The margins of the wound are grasped and retracted with Allis forceps. An assistant places a finger in the rectum and carries the floor of the prostatic bed upward into the opening of the bed. With the aid of a Cameron light, bleeding points are ligated, and, with a curved needle of proper size and shape, the walls of the bed are approximated laterally up to the torn end of the urethra. A soft rubber catheter is then carried into the bladder through the urethra and left in; a large rubber tube is placed in the bladder and the wound is closed up to this tube. A small piece of rubber-dam is placed in the prevesical space and removed on the second day. The suprapubic tube is taken out as soon as the urine is clear, and the catheter is left in the bladder until the suprapubic wound has closed, after an average of from ten to fifteen days.

Deaver expressed the belief that this technic minimizes the possibility of bleeding and infection. He does not advise closure of the prostatic bed in a badly infected bladder. He does not believe that closure of the prostatic bed is so easily accomplished in the two-stage operation on account of the more limited space and the lessened flexibility of the tissues following the primary operation.

Deaver applies his method to the large prostatic bed, which shows little tendency to contract or to ooze in spite of irrigation and hot water. With the floor of the bed and the anterior wall of the rectum carried upward by the finger of the assistant in the rectum, chromic catgut sutures may be readily inserted. There is no danger of injuring the wall of the rectum, the assistant's finger and the fascial and muscular covering of the bowel being enough in evidence to allow avoidance of accidents if the needle is manipulated gently. Deaver stated the belief that his technic is less likely to be followed by contraction and stricture than the bag or gauze pack method.

[COMPILERS' NOTE.—One of the advantages of this method would seem to be the almost immediate epithelization of the prostatic bed, a good principle in all urethral surgery. If such epithelization can

44. Deaver, J. B.: Closure of the Prostatic Bed in Suprapubic Prostatectomy, Ann. Surg. **88**:118, 1928.

be maintained from the beginning, better healing will unquestionably ensue. Difficulties may be encountered in certain types of cases in which the prostatic enucleation has been accompanied by considerable trauma to the mucosa, which would lead to trouble in accurate approximation of the end of the urethra to the mucous membrane of the orifice of the bladder.]

Fullerton [45] stated that prostatectomy has been made less a formidable operation as a result of suitable preoperative preparation and the methods employed to control hemorrhage. The problem of infection due to inadequate drainage has not yet been solved satisfactorily. Drainage by the suprapubic route is not altogether satisfactory.

Fullerton now institutes drainage in cases of suprapubic prostatectomy through the perineum after removal of the prostate gland. The operation is carried out as follows: An incision is made in the perineum on one side, parallel to the ischiopubic ramus, and then crosses a transverse line from the bulb to the anterior part of the tuberosity of the ischium. The incision involves the skin only. The index finger of one hand is then introduced; the base of the triangular ligament is felt and the finger is passed forward to the prostate gland. In doing so it passes above the levator ani muscle. A plug of gauze is temporarily packed into the wound and the patient is placed in position for suprapubic prostatectomy, which is carried out in the usual way. With one index finger in the prostatic cavity and the other in the perineal wound, the thickness of the septum to be traversed by the forceps is estimated. The septum in some cases is almost as thin as a sheet of note paper. It is readily perforated by a long forceps, and a drainage tube about 1.25 cm. in diameter is drawn through. As it is essential to drain both the prostatic cavity and the bladder, the tube is passed well into the bladder; it is perforated by large holes up to the point at which it leaves the prostatic cavity for the ischiorectal fossa. A suprapubic drainage tube is also left in place. The perineal tube should then be left in place until the suprapubic wound has healed, and it should be clamped from time to time to encourage normal urination. The perineal wound does not leak, and on removal of the tube it heals without incident. Fullerton has not observed any infection of the ischiorectal fossa or any leakage through the perineal wound either during the time the tube was in position or after its removal. As soon as normal urination is established, the tube is removed.

Young [46] stated that he has watched Fullerton carry out his method of draining the bladder and prostatic cavity through the perineum in two cases. The procedure is done rapidly and adds little to the dura-

45. Fullerton, Andrew: Drainage of the Bladder Through the Perineum After Suprapubic Prostatectomy, Brit. J. Urol. **1**:7, 1929.

46. Young, H. H.: Discussion, Brit. J. Urol. **1**:15, 1929.

tion or the complexity of the operation of suprapubic prostatectomy. Excellent drainage is obtained of the prostatic cavity from which the hypertrophied lobes have been removed, and also from the bladder, without any possibility of injury to the urethral sphincter or important vessels or nerves in this region. He stated the belief that this method affords an excellent opportunity for dependent perirenal drainage of the bladder and prostatic cavity, the absence of which has been one of the chief objections to suprapubic prostatectomy. From the ease with which the prostate gland is reached by this operation, Young suggested that abscess of the prostate gland and perhaps other conditions might be dealt with by this route.

Carcinoma.—Barringer,[47] in order to illustrate the futility of treatment in most cases of carcinoma of the prostate gland, classified 202 consecutive cases with reference to the duration of life after examination and treatment. Eighteen of the 202 cases were not traced to termination. Fifteen patients lived more than three years, six lived more than four years, six lived more than five years and three lived more than seven years. Only thirty patients (15 per cent) lived for a reasonable length of time after the first examination. Only a moderately small number of those with extensive disease were benefited by treatment.

In any attempt to control carcinoma of the prostate gland, Barringer considered it essential that every man aged 55 or more should be examined by rectum with the same regularity with which blood pressure, heart and urine are examined. Ewing stated the belief that the retention of irritating secretions and inflammatory changes play some part in carcinoma of both the prostatic gland and the breast.

Certain prostatic carcinomas (approximately 5 per cent) are greatly affected by irradiation by means of either radium or the roentgen ray. If the patient is in excellent condition and has not lost weight, he should have one course of deep roentgen treatment to determine whether the carcinoma is radiosensitive. Barringer gathered evidence, from both pathologic specimens and clinical data, to show that operation rarely removes all of the prostatic carcinoma. Operation should be followed by persistent irradiation of the prostatic bed and the lymphatics around the seminal vesicles.

Fifteen of a series of twenty patients with papillary carcinoma of the bladder were free from carcinoma during the period of observation; eleven had been observed for more than five years. Of fifty-one patients with infiltrating carcinoma of the bladder, eighteen were free from the disease; twelve had been free for more than five years.

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47. Barringer, B. S.: Carcinoma of the Prostate and Bladder, New England J. Med. **198**:117, 1928.

Previous to 1927, Barringer made ninety-four suprapubic implantations of radium in ninety cases, with a mortality of slightly more than 3 per cent. Operation was performed in two cases; both patients died. One patient, who was operated on three times, was alive and free from carcinoma seven years after the first operation. There were five cases of papilloma, ten of papillary carcinoma and seventy-nine of infiltrating carcinoma. The mortality after radium compared with the mortality after operative removal of carcinoma of the bladder (between 10 and 20 per cent) shows that by the use of radium a good number of lives might be saved.

Barringer pointed out several significant factors in the performance of the suprapubic implantation of radium: (1) the contents of the bladder should not be spilled into the open wound; this is best prevented by emptying the bladder by means of an aspirating device, padding the wound well, and removing any soiled pads after the bladder is empty; (2) removal by cautery of the quickly heating electric type of protruding parts of the tumor to minimize bleeding and control infection; this method is particularly valuable if the tumor is of the sloughing, badly infected type; (3) if the tumor is large and if bleeding has been severe, or if the bladder is badly infected, drainage should be instituted; a rubber drainage tube should be inserted and removed when bleeding has stopped or when infection has been controlled, generally at the end of several days, and (4) the radium method of choice is the implantation of gold tubes of radium, of a strength of about 2 cm., placed 1.5 cm. apart throughout the base of the growth.

[COMPILERS' NOTE.—Barringer's statistics are noteworthy, confirming as they do the rather ominous outlook for cure in carcinoma of the prostate gland, regardless of the type of treatment employed. The report of Bumpus (1926) from the Mayo Clinic revealed clearly how futile efforts in this direction have been. At that institution, surgical or radiotherapeutic procedures are not usually employed except in cases in which there is definite obstruction or in which the condition is discovered in the course of prostatectomy for lesions which are clinically benign.

However, Barringer and Young have not been so pessimistic and stated the belief that, although cure from radium or prolongation of life may seldom be effected, yet its application, together with deep roentgen treatment, may frequently make the patient more comfortable. Young has also reported a few cases of cure over a period of years from his radical operation. Practically, it would seem from the statistics available that there is little to offer the patient with prostatic carcinoma except in early cases in which carcinoma is found in hypertrophied prostate glands after surgical removal. Here intensive roentgen or radium treatment or a combination of both is said to give fair results.

Barringer has long been an advocate of the method of implanting radium seed in papillary carcinoma of the bladder. Even yet the clinicopathologic classification of neoplasm of the bladder is confused, although the work of Broders in grading these tumors seems to be gaining acceptance and is doing much to stabilize ideas on the subject. Thus Bumpus, in a recent article, designated epitheliomas graded 1 or 2 (Broders' classification) as amenable to successful treatment by endoscopic fulguration, cauterization or electrocoagulation by diathermy through a cystotomy opening when the growth is extensive. Tumors graded 3 and 4 are to be treated by resection or by diathermy applied through the open bladder when the extent and site of the growth makes resection impossible. The patient is enjoined to report for cystoscopic examination every few months; at such times recurrences are diligently sought and, if found, fulgurated. Thus urologists at the Mayo Clinic write in a hopeful spirit, and their initial results seem to justify the method. Nevertheless there are those who follow Barringer and believe that implantation of radium seed still has a distinct field of usefulness.]

Wildbolz [48] stated that operative procedures in cases of prostatic hypertrophy are successful and satisfactory. The operation is still a formidable procedure and has not been attended with good results. In the last twenty years a few cures have been reported. Because of the poor results generally obtained from operation, attention was directed to roentgen and radium treatment. Little benefit seemed to be derived from either, and in some instances the growths appeared to be stimulated. In recent years many surgeons have resorted to palliative measures, such as catheterization and suprapubic drainage.

Only in recent years have statistics of operation for prostatic carcinoma become available. Bumpus reported 164 cases, in twenty-one of which the patients were living and well five years after operation. Even if patients were not cured, life was prolonged. Young reported on twenty of his own patients, fourteen of whom (70 per cent) were living and well three years after operation. Marion reported that the majority of patients on whom prostatectomy had been performed for carcinoma was alive and free from urinary distress from one to five years after operation. Two of the patients were alive four and six years after operation, although local recurrence could be demonstrated. Only three of the forty-eight patients appeared to be cured ten, seven and four and a half years after operation. Wildbolz operated on forty patients with carcinoma of the prostate gland. Three of these (7.5 per cent) died after operation of other complications; two were not traced. Thirteen (30.2 per cent) died from one and a half to

48. Wildbolz, Hans: Die Erfolge operativer Therapie des Prostatskarzinoms, Schweiz. med. Wchnschr. **58**:726, 1928.

three years after operation from multiple metastasis or local recurrence; four died from one to three years after operation from intercurrent disease without signs of recurrence. In six cases there was no sign of recurrence from one to three years after operation. Twelve patients (30 per cent) lived longer than three years without any sign of recurrence, but two of them died of recurrences six and nine years after operation; they had been regularly examined and had not shown signs of carcinoma until the stated time. A third patient died fifteen years after operation, at the age of 85 years, from severe cystitis, but without evidence of prostatic enlargement. Wildbolz had observed the condition of this patient for ten years without noting signs of recurrence. Of the remaining patients who lived longer than three years and were free from recurrence, one lived nine years after operation, two lived six years, and one patient lived five years. Five patients are still living fourteen, ten, six and four (two patients) years after operation.

The condition was operable in only forty of the 145 patients; 105 were treated symptomatically and died in from one to three years. Wildbolz stated the belief that early diagnosis is one of the prime factors in any attempt to cure carcinoma of the prostate gland by surgical measures. Symptoms of prostatic carcinoma are not apparent until late in the course of the disease. According to the literature, in from 15 to 20 per cent of the cases of prostatic enlargement the condition is malignant. Wildbolz noted that one of every five to six patients with prostatic enlargement had carcinoma. Bleeding from the gland has been found to occur only rarely in carcinoma; it usually occurs in benign hypertrophy of the prostate gland. Neurologic pains in the region of the perineum, sacrum or thighs are usually indicative of the extension of the tumor outside the prostatic capsule.

Rectal palpation of the prostate gland is the only method of determining carcinoma early. As soon as one or both lobes lose their resilience and become boardlike or nodular, carcinoma is definitely indicated. Inflammatory induration and prostatic calculi should be differentiated. Stones are to be differentiated by a crunching sensation on palpation. Most inflammatory tissue is not so hard as carcinomatous tissue, although there are difficult borderline cases. Wildbolz erred in the diagnosis in two cases. Carcinoma of the prostate gland is not always to be felt rectally. The soft type of malignant growth is rare. Young found seven cases in 250 cases of prostatectomy. Wildbolz found three cases in his series.

Wildbolz agreed with Young that the perineal route is superior to the suprapubic for prostatectomy, since there is always a possibility that carcinoma will be found. By this route the prostatic capsule and seminal vesicles may be removed if necessary. By cutting through the

prostatic capsule, carcinoma may be identified even before enucleation is begun; thus it is possible to change the operative technic. Even with complete resection of the prostate gland and capsule, the sphincters may be seen and saved, and continence will be as satisfactory as after the suprapubic operation. Wildbolz stated that the objections, prolonged healing of the wound, the formation of fistula, and incontinence, have not been encountered in his cases in which operation has been performed by the perineal route.

[COMPILERS' NOTE.—It is unfortunate that there is no criterion for the early diagnosis of malignant conditions of the prostate gland. If such a diagnosis can be made by palpation rectally or by biopsy by the urethra, frequently the process is too far advanced for surgical procedures to offer anything more than palliation. Methods of obtaining tissue by perineal incision are mainly unsatisfactory. Also, the symptoms are often obscure and the patient and the family physician confuse the condition with arthritis, sciatica and neuritis until the disease is advanced. Bumpus, in a review of a large number of cases, stated his belief that the best chance for cure is in the early cases in which histologic diagnosis has been made from the gland that has been removed presumably for benign disease. Since the incidence of carcinoma in disease of the prostate gland is one in five or six, and the suprapubic operation is totally inadequate for the treatment of malignant disease, we agree with Wildbolz that this is one of the strongest arguments for the perineal operation in prostatic hypertrophy.]

Abscess.—Peterson [49] stated that abscess of the prostate gland may occur by direct extension of a gonorrheal infection in the posterior part of the urethra, or by metastatic involvement of the gland and from some distant or general infection.

Peterson reported seven cases of abscess of the prostate gland. In operating he introduces the Young prostatic tractor into the bladder in order to pull the prostate gland against the perineum. He uses the inverted U-incision, the skin and fat being cut through. Blunt dissection is then carried out on each side of the central tendon of the perineum, with exposure of the prostatic capsule. The central tendon is not severed but is pulled to one side of the median line by narrow-bladed retractors. A longitudinal incision is made into the gland and the cavity is explored with the finger to break down any septums.

Peterson noted that softening and fluctuation of the prostate gland is not a constant observation in the presence of an abscess. In some cases he was not certain that abscess existed until the capsule itself had been incised and blunt forceps had been introduced into the substance of the gland.

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49. Peterson, Anders: Prostatic Abscess, J. A. M. A. **92**:130 (Jan. 12) 1929.

Cumming [50] reported a case of sudden massive destruction of the prostate gland, with resulting dysfunction of the bladder. Retention, incontinence and severe secondary hemorrhage were complications. A complete history, cysto-urethroscopic studies and urography are significant factors in making the diagnosis. Satisfactory surgical intervention consisted of merging of the bladder and the extravesical pseudodiverticular cavity.

URETHRA

Tumor.—Fukai [51] reported four cases of carcinoma of the urethra in men; two patients died following operation. Primary carcinoma of the male urethra is relatively rare; only eighty-four cases were noted in the literature, including those reported by Fukai. In fifty-five cases (60 per cent) there was a history of gonorrhea and in 12.7 per cent a history of trauma. It was often found that the carcinoma had developed on a gonorrheal or traumatic stricture. The seat of the disease was most commonly in the pars cavernosa, with predilection for the bulb or the structures in its vicinity. The early symptoms are similar to those occurring in ordinary stricture. Fukai stated the belief that every stricture and subsequent condition should be investigated for carcinoma, especially if the stricture has occurred in old age without a history of gonorrhea or if it becomes rapidly worse. Gumma should be eliminated in the diagnosis; although of infrequent occurrence, it can easily be confused with carcinoma. Early operation is desirable.

In sixty-two cases there were thirty-four radical operations, with sixteen deaths; in the remaining twenty-eight cases the mortality was 71 per cent. Histologically, the condition in all cases is squamous cell carcinoma. The determination of glandular metastatic carcinoma can be made only histologically.

Huggins and Curtis [52] reported a case of carcinoma of the urethra of a man in which they observed the indolent course of the lesion. Carcinoma of the urethra may cause periurethral abscess and stricture, which clinically are not distinguishable from the usual variety of primary types. If biopsy is to be effective in the diagnosis, it must include the urethral mucosa. The results from radical operation were apparently good.

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50. Cumming, R. E.: Bladder Dysfunction Following Prostatic Abscess, J. A. M. A. **92**:128 (Jan. 12) 1929.

51. Fukai, A.: Ueber das primäre Carcinom der mannlichen Urethra, Acta derm.-venereol. **11**:1, 1928.

52. Huggins, C. B., and Curtis, G. M.: Carcinoma of the Male Urethra with a Technique of Penis Extirpation, Surg. Gynec. Obst. **48**:544, 1929.

Obstruction.—Young and McKay [53] stated that congenital obstruction of the prostatic urethra always occurs as one of three types. In the most common type there is a ridge lying on the floor of the urethra, continuous with the verumontanum, which takes an anterior course and divides into two forklike processes in the region of the bulbomembranous juncture. These processes continue as thin membranous sheets, directing upward and forward, which may be attached to the urethra throughout its entire circumference. In most cases of this type, the fusion of the valves anteriorly is not complete. Slight separation of the folds exists at this point. In the second type there is a more or less cylindric ridge similar to that found in the preceding type, with the exception that it passes over the upper aspect of the verumontanum toward the internal sphincter. It divides into two forklike processes, which continue as membranous sheets and are attached to the urethra outside the internal sphincter. The third type has been found at different levels of the posterior urethra and apparently does not bear any relation to the verumontanum. It is similar in shape to the iris of the eye. This obstruction is attached to the inner circumference of the urethra, there being a small opening in the center.

The symptoms may be those brought about by local obstruction to urination, or from the backpressure on the kidneys producing renal injury, insufficiency and uremia. There may be dribbling, frequency, and incontinence, of the type which results from the overflow of a distended bladder which never becomes completely emptied.

Careful abdominal examination should be made to determine whether the bladder, ureters and kidneys are palpably dilated. Instrumentation of the urethra should be carried out delicately to detect the valves, to note the position, and, if obstruction is met, to find the instrument, generally a small pointed urethral catheter, which can be passed through the slit between the valves to catheterize the bladder. Cystoscopic examination should be carried out as soon as the condition of the patient permits. By careful manipulation of a child's small cystoscope, the slit between the two valves can usually be penetrated.

Practically the same preparatory treatment is necessary in these cases of prostatic urethral obstruction as in cases of prostatic hypertrophy with marked backpressure and much residual urine. Drainage should be maintained until the drop in nonprotein nitrogen and increase in output of phenolsulphonphthalein are sufficient to warrant the slight operation necessary to remove the valves.

A number 7 French punch instrument is passed into the urethra, and, by careful manipulation, through the aperture between the valves

53. Young, H. H., and McKay, R. W.: Congenital Valvular Obstruction of the Prostatic Urethra, Surg. Gynec. Obst. **48**:509, 1929.

and on into the bladder. The bladder is then washed out and filled again with a weak antiseptic solution. Only one valve is removed at the first operation. If the obstruction has not been completely relieved, it may be advisable to make another cystoscopic examination to determine the presence of a remaining valve and to make an additional cut with the punch instrument on the opposite side. Fulguration was first carried out by means of the high frequency current and a ureter-catheterizing cystoscope, the valves being destroyed by fulguration. The prognosis depends largely on the extent of the obstruction, the character of the renal impairment, and the general condition of the patient.

Young and McKay reported twenty-one cases of a congenital valve of the posterior urethra observed at the Brady Urological Institute, in fifteen of which operation had been performed successfully. Nine of the patients were less than 16 years of age. The authors reviewed forty-one cases from the literature, in twelve of which operation was performed.

Diverticulum.—Gorowitz [54] stated that diverticula of the urethra in females are not congenital. They occur late in life by the influence of various mechanical, traumatic or inflammatory acquired factors. They often remain latent for a long period and become manifest through secondary conditions, such as infection, inflammation, and sometimes disease of the bladder. Palliative treatment is unsatisfactory; the best results are obtained by operation.

Stricture.—Campbell [55] reported a study of 1,244 cases of stricture in the urethra of the male. He concluded that more than 90 per cent of such strictures are of inflammatory origin, and that the condition depends on the severity of the urethritis rather than on the duration. Usually the strictures are multiple clinically, although they may be single pathologically. Traumatic strictures are usually single. Nephropathy secondary to obstruction by stricture is of significance. The author treats stricture on the basis of renal injury and infection. Dilatation is the nonoperative or palliative treatment, and its employment must be persistent and prolonged. The indications for operation are failure of response to dilatation, and certain complicating infections. Strictures of the pendulous urethra and scrotal bulb are cut by internal urethrotomy, preferably under spinal anesthesia. An indwelling catheter provides drainage of the bladder and checks bleeding. For deeper strictures perineal section is usually necessary, in which case a perineal bladder tube should always be used. Extensive multiple

54. Gorowitz, P.: Ueber Divertikel der weiblichen Harnöhre, Ztschr. f. Urol. **22**:183, 1928.

55. Campbell, M. F.: Stricture of the Male Urethra, Ann. Surg. **89**:379, 1929.

strictures may require both external and internal urethrotomy. Dilatation with sounds, beginning from seven to ten days after urethrotomy and continuing every five or ten days thereafter until the canal maintains a normal caliber, should be performed, with rare exception. Numerous postoperative complications may develop, many of which are potentially fatal. The immediate mortality is about 5 per cent. Most patients are improved by operation. A third will require reoperation, two thirds of these within ten years. Gentleness is a prime consideration in all urethral instrumentation. Campbell stated the belief that it is of greater importance than asepsis.

Flandrin [56] stated that suprapubic drainage, which is so frequently resorted to in cases of traumatic rupture of the urethra, hypospadias, and resection of traumatic strictures, has given, in Legueu's service, excellent results when used as the first-stage operation in cases of complicated stricture of the urethra. Flandrin gave the following indications for its use: strictures which render catheterization difficult and which are accompanied by distention of the bladder; tight and multiple strictures associated with extensive urethral infection and balanitis; tight and hard strictures accompanied by localized subacute periuerthritis, and tight and hard strictures, with fistulous or nonfistulous chronic periurethritis.

TESTES, EPIDIDYMIS AND SEMINAL VESICLES

Undescended Testes.—Higgins and Welti [57] stated that statistics compiled by various authors agree regarding the frequency of undescended testes. Marshall reported an incidence of 1.02 per cent in 10,800 men examined. Ziebert, in examination of men for the Austrian army, reported 14,057 cases among 6,962,543 men, an incidence of 0.2 per cent.

Faulty descent of the testis occurs most commonly on the right side. Grossly, the undescended testis is usually smaller, less elastic, and less firm in consistence than is a normal testis. Ombrédanne observed that before puberty an ectopic testis looks, on section, like a normal child's testis. Its epithelial cells are normal. The interstitial cells are proportionately more numerous than those of an adult's testis, but this is normal in a child. After puberty the interstitial cells are numerous, which is an argument against orchidectomy, if it can be avoided. Only a few spermatogones are found after puberty, rarely spermatids, and never spermatozoids. If an operation is to be useful,

56. Flandrin, P.: La cystostomie hypogastrique temporaire dans le traitement des rétrécissements compliquées de l'urètre, Paris méd. **69**:335, 1928.

57. Higgins, C. C., and Welti, H.: Surgical Treatment of Undescended Testicles, Surg. Gynec. Obst. **48**:536, 1929.

it must be done before puberty because at that time the testis is normal and it can be hoped that if the testis is placed in a normal position it will grow normally.

Of 452 cases of malignant growths of the testis reported by Cunningham, 412 occurred in normally placed testes. Ombrédanne pointed out that, although a malignant growth is frequently observed in these cases, it occurs only in adults. Torsion may also occur, especially in cases of so-called migrating testes. In these cases, because of a congenital deficiency in the internal oblique muscle and its conjoined tendon, the testis can more readily be moved upward and downward. The association of an undescended testis with hernia has long been recognized. In a series of 80,736 cases of hernia there were 1,357 undescended testes. Atrophy results if the testis is not restored to the normal position.

There are various opinions as to the correct age for operation. It should be done before the age of puberty is reached, and preferably between the ages of 8 and 12 years. If by manipulation the testis can be brought to the bottom of the scrotum, operation is contraindicated, since under these circumstances descent will always occur at the age of puberty. If the testis cannot be found clinically, operation is indicated.

Higgins and Welti performed transscrotal orchidopexy, a procedure which has been performed by Ombrédanne for twenty years in many hundreds of cases. The usual incision for inguinal hernia is made, and the anterior wall of the inguinal canal is incised. The cord is then exposed and isolated. The canal is explored. A radical operation for hernia should be performed at this stage. If the canal is not occupied by a hernia, obliteration of the canal is not necessary, since it will close spontaneously after operation if the wall of the inguinal canal has been restored in front of it. A sliding knot is then placed above the gland and the testis is covered with a warm compress. The scrotal raphé is marked with two clamps and is held gently. With the left index finger, a passage is made into the scrotum, beginning at the inguinal incision, and progressing toward the middle of the sac diagonally opposite. When the elastic septum is reached, it is forced back and the skin of the scrotum on the opposite side is raised. On the side of the scrotum elevated by the index finger, a vertical incision approximately 3 cm. in length is made. The septum becomes visible, being recognized by its white color. By means of a compress the two cutaneous lips are pushed back along the finger which is pushing the septum in the inverse direction. Separation is thus accomplished and a place for the testis is secured. The septum, which has been elevated by the index finger, is pushed back, is grasped above and below, and is then incised vertically between clamps. The free ends of the catgut,

the slip-knot of which has been placed around the neck of the gland, are grasped and brought through the opening in the septum.

[COMPILERS' NOTE.—In this country the operations of Bevan and of Torek for undescended testes have been much in vogue during the last few years, and the operation of Ombrédanne seems to have been seldom used. As described by Higgins and Welti, this operation has the advantage of being a one-stage procedure, so far as each side is concerned, and is more easily applied if the vas deferens is short. The excellent results reported seem to indicate that the Ombrédanne technic is worthy of trial.]

Tuberculosis.—Hinman [58] stated that one of the prominent characteristics of genito-urinary tuberculosis is its tendency to spread from one part of the tract to the other, regardless of whether the primary lesion is in the urinary or genital tract. Renal tuberculosis in the male is more common than genital tuberculosis, the average incidence of which is 0.5 per cent, whereas that of renal tuberculosis is estimated as from 1 to 5 per cent.

Of Hinman's fifty-one cases of genital tuberculosis, only twenty (39.4 per cent) were primary in the genital tract; the others were associated with active tuberculosis elsewhere in the body. A significant clinical fact in the treatment of renal tuberculosis is that the infection begins in one kidney and is manifested in the other kidney in the late stages of the disease except in cases of a miliary type. Early nephrectomy is the treatment of choice to prevent extension of the disease to other parts of the tract.

Whether the primary lesion in genital tuberculosis occurs in the epididymis or seminal vesicle and prostate gland is still a controversial subject. Those who maintain that the primary focus is in the epididymis point out that primary tuberculous epididymitis is frequently observed to occur independently, whereas if genital tuberculosis exists, the whole tract is generally involved, the spread being from the primary lesion in the epididymis. The extent of a lesion cannot be taken as an indication of its duration; involvement of the opposite epididymis may be hematogenous. Lesions in the epididymis may have been overlooked in cases in which the lesion was supposedly in the prostate gland and the bladder primarily. In the majority of cases simple epididymectomy effects improvement or arrest of the lesion recognized clinically as in the bladder and in the prostate gland. Tuberculosis of the seminal vesicles and prostate gland is rarely recognized in the absence of involvement of the epididymis. The presence of tuberculosis in the seminal vesicles or prostate gland, as indicated by the

58. Hinman, Frank: The Surgical Treatment of Lower Tract Tuberculosis, Genital and Vesical, J. Urol. **20**:521, 1928.

presence of nodules, without evidence of disease in the epididymis, is more common. Tuberculous epididymitis rarely occurs alone, and it is often preceded by symptoms of vesiculitis or prostatitis Whenever the epididymis is affected by tuberculosis, the initial lesion is in the globus minor; the globus minor is also first involved when the disease spreads to the opposite epididymis. From the globus minor it extends to the body and globus major, making a 100 per cent involvement of the globus minor. Pathologic facts supporting the belief that the lesion is primary in the seminal vesicles or prostate gland are: (1) lesions of the epididymis alone are rarely found at necropsy, whereas tuberculous lesions of the seminal vesicles and prostate gland unaccompanied by lesions in the epididymis are frequently reported; (2) in cases in which the disease affects the whole genital tract, the lesions in the seminal vesicles and prostate gland generally have the appearance of being more advanced and older, and (3) lesions in the globus minor of the epididymis appear to be older and more advanced than those of the body or globus major.

Hinman observed seventeen cases of epididymitis without clinical evidence of vesiculitis. In eleven cases simple epididymectomy was performed; in six cases the treatment was nonsurgical. Five patients were not traced. Of those operated on, four had bilateral epididymectomy, four had right epididymectomy and three had left epididymectomy. Three of these eleven patients have had nephrectomy, and three have been lost from observation. Four patients, eight, seven and three years and five months after operation, stated that they were better than before surgical treatment. Three patients died after leaving the hospital, two of tuberculosis and the other apparently of acute pneumonia. Of the six patients not treated surgically, two had left nephrectomy subsequently. One of the remaining four patients was heard from four years after examination, and at that time his general condition was good. One patient was not traced, and two patients are dead, both of tuberculosis. To summarize, of the twelve patients who were traced six are alive and six dead, three of whom had had epididymectomy.

Hinman observed a second group of seventeen patients in whom the seminal vesicles showed clinical evidence of involvement. Five were treated by epididymectomy, and twelve were not treated surgically. Nine patients were traced; six were alive and three were dead. Five of the nine had had simple epididymectomy, which was bilateral in four. Two patients were improved four and six years after operation, two were worse, and one died of embolism six days after epididymectomy. Of the twelve patients not treated surgically, four had evidence of bilateral tuberculous epididymitis, one patient had evidence of right epididymitis, and three patients of left epididymitis. The four remain-

ing patients with involvement of the seminal vesicles did not show evidence of involvement of the epididymis. Six patients also had urinary tuberculosis; three showed evidence of tuberculosis in both kidneys; two in the right kidney alone, and two in the left kidney alone. Four of these had vesical involvement.

In a third series there were thirteen patients with tuberculosis of the entire genital tract. Radical bilateral epididymectomy, vasectomy, seminal vesiculectomy, and in some cases partial prostatectomy were performed. Two of these patients were dead, both were poor surgical risks, two had not been traced, and nine were living and well. The results in these nine patients have been satisfactory except for a perineal sinus which persisted for months to a few years in cases in which partial prostatectomy was performed.

Tuberculous ulceration of the bladder is common in both renal and genital tuberculosis. Of 148 patients with genito-urinary tuberculosis, 110 had cystoscopic evidence of active tuberculosis of the bladder. After removal of the primary focus in the genito-urinary tract, the lesions of the bladder often healed spontaneously.

Hinman concluded that there are two clinical types of genital tuberculosis: (1) that in which the more advanced or only lesion is in the epididymis, and (2) that in which the seminal vesicles are involved with or without epididymitis. If the primary focus is in the epididymis and not assocated with active lesions elsewhere, the indication is for epididymectomy, and if the seminal vesicles are involved the radical operation should be performed.

Eisenstaedt [59] found that it is possible for a patient to have right epididymitis of tuberculous origin, the left half of the prostate gland being involved by tuberculosis and possibly the right orchis. He had been successful with treatment by the roentgen ray, and operates only if necrosis and secondary infection necessitate drainage.

Süssig, working under Ghon in Prague in 1921, examined between 130,000 and 180,000 serial sections in cases of urogenital tuberculosis. He found that in the majority of cases the term, primary, could not be accurately applied, even if it was confined to the urogenital tract. The bacteria were found in multiple portions of the urogenital tract in many of the cases.

McKenna,[60] in 104 postmortem examinations in a comparative study of tuberculosis of the genito-urinary tract, found eight cases of primary lesions in the epididymis and three in the prostate gland and vesicles, showing that they occurred two and a half times more commonly in the epididymis than in the prostate gland or vesicles. He noted that

59. Eisenstaedt, J. S.: Discussion, J. Urol. **20**:539, 1928

60. McKenna, C. M.: Discussion, J. Urol. **20**:539, 1928.

patients suffering with tuberculosis of the epididymis, vesicles or prostate gland do well if they are treated by tuberculin and the direct rays of the sun.

UROLOGIC SURGERY

Hunt [61] reported that at the Mayo Clinic during 1928 there were 881 operations on the kidneys, ureters and bladder, with thirty-four deaths, a mortality rate of 3.8 per cent. In 117 operations for malignant lesions, there were eleven deaths (9.3 per cent), whereas in 764 operations for benign disease there were twenty-three deaths (3 per cent).

Lithiasis was the predominating lesion of the kidney, for which there were 133 operations without a death. Infection and destruction of renal tissue were so marked that nephrectomy was necessary in forty-seven cases (33 per cent). Pelviolithotomy was utilized in the removal of single and multiple stones from the kidney in 87 per cent of the cases. During the last two years pelviolithotomy and nephrolithotomy have been performed in 164 cases without mortality. Nephrectomy was performed in 200 cases: for renal tuberculosis in fifty-two cases, for nephrolithiasis in forty-six, for hydronephrosis in forty-three, for pyonephrosis in seventeen, for pyelonephritis in twelve, for a malignant growth in twenty-seven, for multiple cysts of the kidney in two, and for rupture of the kidney in one case. There were five deaths following nephrectomy.

The malignant lesions of the bladder are most formidable; approximately only 50 per cent of the lesions are operable. Palliative suprapubic cystostomy is sometimes used in cases of inoperable lesions, and these contribute considerably to the mortality of cystostomy for the various conditions in which it is necessary. Operations were carried out in thirty-two cases. The procedures of choice for lesions of the dome and the posterior lateral walls of the bladder are segmental resection and excision, and in lesions of a low grade of malignancy they have been productive of the best results. Surgical diathermy is being used with considerable success in lesions of the base of the bladder with involvement of one or the other ureter. Disposition of the ureters is a significant problem because one or both ureters are usually dilated and unsuitable for transplantation into the sigmoid.

Diverticula of the bladder have been removed in twenty-four cases. In most instances they were large, were associated with prostatic obstruction, and were removed preliminary to prostatectomy.

There were 265 prostatectomies, of which 249 were for benign prostatic hypertrophy and sixteen for malignant disease. There were

61. Hunt, V. C.: Report of the Major Surgical Procedures on the Kidney, Bladder and Prostate at the Mayo Clinic for 1928, Proc. Staff Meet. Mayo Clinic **4**:86, 1929.

twelve deaths in cases of benign prostatic hypertrophy (4.8 per cent). Perineal prostatectomy was done in nine cases, with excellent recovery in all. The other patients were all operated on by the suprapubic method; the one-stage operation was employed in 69 per cent of the cases. Those patients who had had preliminary cystostomy recovered from the condition requiring cystostomy and arrived at a stage of improvement so that prostatectomy was undertaken as a second step, with a mortality of 3.9 per cent. For the year the mortality was 4 per cent following preliminary cystostomy performed as the first step of two-stage prostatectomy, as a result of the poor condition of the patients at the time that cystostomy was necessary. The average age of patients who died following simple cystostomy preliminary to prostatectomy was seventy-seven years.

In prostatic surgery, age is an important factor in mortality rate and should be considered in determining the advisability of prostatectomy and the methods of procedure. In a review of 1,973 prostatectomies, with nearly as many patients more than 65 years of age as there were less than 65 years, a definite relationship between age and mortality rate was established. The average mortality before the age of 65 years was 3.9 per cent; after 65 it was 6.3 per cent. The rate rises rapidly after the age of 70, which emphasizes the necessity for most careful consideration of prostatic obstruction in the aged.

CHYLURIA

Wood [62] reported a case of chyluria which originated in the left kidney. Examination did not reveal eosinophilia, or parasites or ova in the blood, urine or stools. The chyluria first occurred at the age of 15 and cleared up without treatment. It recurred at the age of 71 years. The differential phenolsulphonphthalein tests showed the output of the left kidney to be more than that of the right on account of right-sided nephrosis. A pyelogram of the left kidney revealed an apparent communication between the extrarenal pelvis and the aortic lymph nodes in the vicinity of the pelvis. Such a communication was not observed on the right side. The chyluria ceased after pyelography, without other treatment, and the condition has not recurred.

LABORATORY TECHNIC

Blanc [63] reviewed his method of making a phenolsulphonphthalein test; he injected 4 cc., representing 6 mg. of the product; 70 per cent of this should be eliminated in an hour and ten minutes. From the

62. Wood, A. H.: Unilateral Renal Chyluria, J. Urol. **21**:109, 1929.

63. Blanc, H.: Les lois de l'élimination de la phéno-sulfophtaléine; leur valeur en chirurgie urinaire, Paris méd. **69**:331, 1928.

numerous tests which he carried out, he drew several conclusions. The rate of phenolsulphonphthalein of separated or total urines has a great value by itself, as far as an absolute rate is concerned, without considering the amount of urine excreted during the time of exploration. The rate of elimination of the phenolsulphonphthalein represents exactly the functional value of the renal parenchyma, but it is not necessarily a measure of the anatomic value nor of the function of the tubular apparatus. It constitutes an expression of the physiologic value more than the anatomic value. It decreases proportionately with the distention or the destruction of the kidney. In cases of healthy kidneys the rate of output of phenolsulphonphthalein in total or separated urines remains about the same, regardless of the time the urine has been collected. In cases of healthy or diseased kidneys, without any lesions of the active glandular cells, the output of phenolsulphonphthalein remains constant as long as the functional value remains constant. If a diseased kidney shows loss of function and diminution in elimination of the phenolsulphonphthalein, the other kidney will increase elimination. On separated urines, there usually will be a parallelism between the uric acid and the excretion of phenolsulphonphthalein. Each functional change which the renal parenchyma undergoes, except in the presence of a long-standing lesion, influences the return of phenolsulphonphthalein.

Cammidge and Howard [64] carried out experiments to find an improved method for titrating sugar in urine and blood. They considered that the methods ordinarily used are too inaccurate or difficult to carry out, except after considerable experience. They use arsenious acid, which is stable in dilute solutions, rather than sodium thiosulphate, which deteriorates rapidly, and they follow the method of Melli for the estimation of calcium. Arsenious acid also gives a readily recognizable and critical end-point.

They consider the advantages of their methods to be that all the solutions are stable and keep for an indefinite period in well-stoppered bottles, that the use of a regulated gas supply is avoided, that a sharp and easily recognized end-point is obtained in the titrations and that accurate results may be secured even by inexperienced workers.

UROLOGY AND GYNECOLOGY

Bonney [65] stated that since the branches of gynecology and urology are so closely associated, specialists in these branches should be reasonably well informed of the work of the other.

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64. Cammidge, P. J., and Howard, H. A. H.: An Improved Method for Titrating Sugar in Urine and Blood, Brit. J. Urol. **1**:17, 1929.

65. Bonney, Victor: Urology in Relation to Gynaecology, Brit. J. Urol. **1**:23, 1929.

It is important to have a thorough understanding of the supporting structures of the pelvis, consisting of the cardinal ligaments and the pubocervical fascia. The bladder rests on this fibromuscular shelf, and any alteration in it affects the bladder. There are three common deformities affecting this shelf. In the first deformity, the pubocervical fascia buckles or hammocks downward to produce a cystocele. The effect on the bladder is difficulty in passing urine and failure completely to empty the bladder. In the second deformity the attachment of the pubocervical fascia at its anterior end becomes weakened, so that, on straining, this end of it droops, which results in interference with the sphincteric mechanism of the bladder. Some form of incontinence results and is produced on effort, such as sneezing, coughing or running. The third deformity is the retroversion of the whole pelvic shelf, so that the line of the vaginal axis protracted beyond the upper end of the canal would strike the sacrum somewhere about its second piece. The vagina retroverts with the shelf, and the bladder moves backward with both of them. It is important to recognize this deformity because of the fact that cystocele is often wrongly diagnosed; pouching of the bladder does not occur in these cases.

In abdominal operations Bonney observed that the more marked the postoperative intestinal symptoms, the more profuse is the bacterial infection of the urine, so that pyelitis in some degree is common. The infection does not always disappear with the healing of the operative area, but may continue for months or years afterward. Postoperative ureteric fistula following the Wertheim operation for carcinoma of the cervix is the result of sloughing of the ureter several days after operation, which leaves from 5 to 7 cm. of these conduits running free across the pelvis. Bonney successfully grafted the ureter into the bladder in many of these cases, a procedure which was made easier because the ureter is always dilated above the point of leakage. Nephrectomy is a hazardous procedure, but there are some cases in which it is necessary, particularly those in which the fistula had existed so long that the kidney on that side is disorganized.

Infection of the vagina by the streptococcus, which is relatively common, may sometimes be an overlooked source of streptococcal urinary infection.

Pyelitis of pregnancy is generally held to be due to the pressure of the enlarging uterus on the ureters. Pelvic tumors other than that of pregnancy rarely cause pressure on the ureters sufficient to obstruct them, even when the tumor is tightly impacted in the pelvis. Innocent growths such as fibromyomas or ovarian cysts rarely affect the ureters, but they may have a marked effect on the bladder, particularly fibromyomas. One of the earliest symptoms of this is increased fre-

quency of urination. An impacted fibromyoma is one of the most common causes of retention of urine among women.

[COMPILERS' NOTE.—The importance of a closer relationship between the urologist and gynecologist is constantly being emphasized, a point which many gynecologists, notably those from the Kelly school in Baltimore, have insisted on for many years.

The changes in the urinary tract incident to gestation, the proximity of the urinary and generative tracts in women, the easy access of the streptococcus or the colon bacillus to the bladder, and the stasis due to pressure changes brought about from pelvic enlargements, frequently force the gynecologist into a detailed urologic study which is enlightening from the standpoint of diagnosis, treatment and prognosis. Whether or not the gynecologist shall be his own urologist is a moot point. It would seem to be common-sense reasoning that this should be determined by the special training and the inclination of the individual surgeon and that a sharp line of demarcation should not necessarily be drawn between the specialties in practice. Every one who professes to be proficient in either specialty should have a reasonable understanding of the fundamental principles involved in the practice of both gynecology and urology.]

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REPORT ON THE ACTIVITIES OF THE CHEST TUMOR REGISTRY

During the past year the recommendations of the Council of the American Association for Thoracic Surgery relative to the establishment of a Registry of Chest Tumors have been carried out. Letters describing the Registry, together with a statement of the types of tumors to be included and registration forms for the submission of material, were sent to all members of the American Association for Thoracic Surgery, the American Surgical Association and the Association of American Physicians, and to the pathologists of the leading clinics of the country.

Up to date the actual number of cases registered has been small, but correspondence between the registrar and a number of surgeons interested indicates that a considerable number of cases are available and should be registered.

The registrar has purposely avoided too active solicitation of material, feeling that the success of such an undertaking depends, in part at least, on its obtaining the spontaneous support of those interested. However, at the suggestion of the Council of the Association, blank forms on which data regarding cases to be registered may be filled in will be circulated to facilitate the submission of material.

The Registry is designed to include all primary intrathoracic tumors and all such other tumors of the chest wall and thoracic vertebrae as impinge on the pleural cavity. The committee requests the cooperation of all interested persons in the registration of such cases.

WILLIAM DEW. ANDRUS, M.D., Registrar,
Cincinnati General Hospital, Cincinnati.

PULMONARY TUBERCULOSIS

PATHOLOGY AND TREATMENT *

JOHN L. YATES, M.D.
MILWAUKEE

There are approximately 625,000 people suffering from pulmonary tuberculosis in this country, 85,000 of whom will die within the year. The total time spent annually in combating the disease by those potentially and actually affected is about 633,333 years, and even so more than two thirds of them suffer one or more recrudescences after apparent recoveries. More than three-fourths are afflicted while their productive and earning capacities would be otherwise little, if at all, impaired. The total of the yearly costs of therapy, exclusive of consultation and attendance fees, and of the losses imposed by deaths after intervals of illness and by the duration and degree of temporary and permanent disabilities of those who survive will amount to $870,000,000.

During the past fifteen years, although the population has increased, the annual death rate has been reduced from 155,000 to 85,000, the incidence from 1,000,000 to 625,000 and the costs by about $250,000,000.[1]

Progress made in combating pulmonary tuberculosis has resulted not only from a clearer perception of its pathology which provided a larger measure of prevention, earlier diagnosis, more effective treatment and after-care, but also from improved housing, schooling, and working conditions, better and cleaner food, more wholesome methods of living, and restricted emigration.

During the same interval, tuberculous cows had been eliminated from dairy herds in some communities. In them the incidence of tuberculosis of bones, joints and lymph glands was reduced to a small fraction of the previous numbers. The few persons who now develop these forms of tuberculosis are more seriously affected, some because of their greater susceptibility to bovine tuberculosis; others are infected with bacilli of the human type. Although other influences, such as greater attention given to teeth and tonsils, were contributory, the elimination of the most dangerous source of infection was the effective agency. Presumably the incidence of pulmonary tuberculosis has also been reduced in the same communities even though the reduction has not been demonstrated by statistics.

---

* Presidential Address.

1. Information from which these figures were obtained was furnished by Miss Aimee Weinstock and Mr. Leslie L. Lewis of the Wisconsin Anti-Tuberculosis Association, who made conservative estimates from the data at their command.

The need to hasten the curtailment of the social and economic burdens imposed by the white plague compels consideration of the chief obstacles to past and present progress. The foremost obstacle is incomplete knowledge of the influences that govern the inception and evolution of the disease. Next, is the lethargy born of satisfaction and subservience to established routinism that prevents application in practice of available knowledge, stifles investigation and assures mass treatment. Last, is the numbing effect of the procrastination that makes a majority of patients realize that nothing aggressive is or will be done to satisfy individual requirements until long after pacifistic therapy has been proved futile, frequently not until approaching death impels attempts to camouflage neglect.

A review of the biologic aspects of extrapulmonary tuberculosis will provide a clearer perception of pulmonary tuberculosis and show why the more effective means to prevention and treatment can be determined by physiology and pathology more accurately and promptly than by any other means.

EXTRAPULMONARY TUBERCULOSIS

INCEPTION

Three conditions are precedent to the inception and evolution of tuberculous processes. Tubercle bacilli must be deposited on the skin and mucous membrane and the peritoneum in females which form the surfaces of the body and are barriers against invasion. (The bronchial mucous membrane and the cells lining the alveoli of the lungs will be considered later.) Bacilli must become invaders of the body by passing these barriers. Once the barriers have been passed, the microbes must be sufficiently robust not only to survive temporarily but also sooner or later to develop parasitic activities.

INVASION

Few exceptions prove the rule that all people but some infants are carriers of virulent tubercle bacilli which have been deposited repeatedly on the surfaces of the body from the air, contacts and ingesta. So long as the bacteria remain under no pressure on a surface, they are innocuous.[2] Invasion of the body begins at a portal of entry in a

2. Normal external surfaces are the skin, mucous membrane, lining of pulmonary alveoli and the peritoneum in females. Normal internal surfaces are: the nutritional, formed by the endothelium lining the vessels of the systemic circulation; the ventilating, formed by the endothelium lining the vessels of the pulmonary circulation; the digestive, formed by the endothelium lining the vessels of the portal circulation; and the drainage surface, formed by the cells lining the lymph vessels. Abnormal surfaces are the deeper tissues exposed by injuries, the surfaces of ulcers and the inner surfaces of the walls of abscesses.

surface and continues by repetition of similar steps. Consideration of the destruction of most of the invading bacilli is omitted for the present to avoid complication.

Bacilli under pressure and those fixed by secretions or exudates enter, pass through or between intact surface cells, pass through superficial lesions or are carried across these barriers within wandering phagocytes. They may be retained in surface cells or at the surface of lesions and may or may not provoke inflammation which usually includes formation of tubercles. Inflammation is provoked by parasitic activities of bacilli, namely, the elaboration of noxious egesta and reproduction. Bacilli that survive but induce no inflammation are for that time saprophytes, i. e., they elaborate so little noxious egesta that adjacent cells are not overactivated and their reproduction suffices merely to prevent extinction.

Having passed the first barrier, they enter the subcutaneous or submucous tissues which constitute another barrier. (Direct contamination of the peritoneum of females is too rare to warrant consideration.) Here the bacilli are under tissue tension. They may be retained in and between cells and produce or do not produce lesions according as they are parasitic or saprophytic. Those deposited on the outer surface of the endothelial cells of blood and lymph capillaries may enter, pass through or between them. More often the bacilli are taken up by phagocytes and carried into the lymph vessels. The naked bacilli and those carried within phagocytes which have entered the blood and lymph streams have passed another barrier presented by the external vascular surfaces and are disseminated. As some dissemination is a prompt and constant consequence of invasion, tuberculosis even in its incipient stage and in its milder forms is a systemic contamination.

The bacilli, naked or within phagocytes, carried in the blood are deposited on the inner surface of the capillary endothelium. Many of those entering the portal circulation are retained in the hepatic capillaries in which the Kupffer cells are present. The others and nearly all of those entering the capillaries in the systemic circuit are carried to the lungs. The few that are not deposited on the walls of the capillaries in the lesser circuit, which will be discussed later, are disseminated in the arterial blood of the systemic circulation. They are deposited on the walls of its capillaries which form the nutritional surface of every organ and tissue in the body. Consequently, every structure is liable to invasion because these microbes may penetrate this barrier, the nutritional surface, just as they pass other barriers. The parenchyma of organs and the cells of tissue present another barrier analogous to the subcutaneous and submucous structures wherein again microbes may or may not provoke inflammation and from which they may or may not be disseminated.

Bacilli enter, pass through or between the cells lining the lymph vessels which constitute the drainage surface of all structures but the central nervous system, eye, internal ear and spleen which have no lymphatics. Bacilli carried in the lymph, whether naked or in phagocytes, are usually deposited on the endothelium of the sinuses in the proximal lymph gland to which they are carried, or they may pass through the sinuses of this gland and be deposited on the sinus walls of the next gland. In lymph glands, reticulo-endothelium forms part of the drainage surface and has a special capacity to engulf and to destroy bacteria. This barrier is less easily passed, but once bacilli have entered the parenchyma of the gland, there is the same sequence of events. The bacilli provoke lesions and are retained or disseminated through blood or lymph vessels or are disseminated or retained without provoking lesions. Ultimately, some of the bacilli that enter the lymph are delivered into the blood through the right or thoracic ducts. The many which penetrate the intestinal mucosa are delivered rapidly, especially during active digestion, into the receptaculum chylae and thence promptly into the blood. Bacilli carried in the lymph formed in tissues outside the digestive tract reach the blood after longer intervals. Not only have they farther to travel but the collateral pathways are fewer. The sinuses within tuberculous glands are often obstructed, and this compels the lymph in afferent vessels to seek unobstructed centrifugal channels which may carry lymph in devious channels through adjacent or even remote regions and thus lead to anomalous dissemination of bacilli but nearly always to lymph glands.

Summary.—The significant phases in the cycles of invasion of the body are:

First Cycle

(1) Dissemination of bacilli through the air

(2) Deposition of bacilli on a normal or abnormal external surface of the body from air, ingesta or contacts

(3) Penetration of an external surface of the body

(4) Deposition of bacilli within subcutaneous or submucous tissue

(5) Provocation of or failure to provoke inflammation

Second Cycle

(1) Dissemination of bacilli through blood and lymph

(2) Deposition of bacilli on a normal or abnormal internal surface of the body

(3) Penetration of an internal surface of the body

(4) Deposition of bacilli within the parenchyma of organs or between the cells of tissues

(5) Provocation of or failure to provoke inflammation

Subsequent Cycles

The first cycle is repeated in all those who survive infancy.

The second cycle is repeated in all those of less than high grades of insusceptibility, continuous in those of lower grades of susceptibility.

SURVIVAL OF TUBERCLE BACILLI WITHIN A BODY

The divers activities of cells are products of metabolism. Individuality of cell structure, the result of differentiation, determines the peculiarities of metabolism and therefore of function. The rate of production of function, i. e., the metabolic rate, is governed by the actions of excitory and repressive influences and is limited by the capacity of cells to respond thereto, namely, by their strength and endurance.

Rates of metabolism and corresponding grades of activities are higher during the periods of exercise and lower during the intervals of rest that alternate throughout cell life. As cells weaken because of untoward alterations in their structure resultant from senility, the fatigue of overexertion, the atrophy of underexertion, trauma, dehydration, malnutrition, starvation and intoxication, the rates of their metabolism in response to positive influences fall proportionately. If metabolism falls below a certain level, the limit of viability, and remains below the level for more than brief intervals, the cells are lethally injured. Death may occur at once. Sometimes the injuries which are progressive are less severe and lead to necrosis after considerable intervals during which some functions are produced.

The limit of viability is not fixed. It is lower if cell structure is stronger and more resistant and is also lower for all cells in a favorable than in an antagonistic environment.

Tubercle bacilli within the body of a host are in an antagonistic environment. In order to survive they must maintain their metabolic rates at or above a limit of viability which is higher than it usually is when they are on an external surface.

The pathogenic activities of bacilli are elaboration of noxious egesta and reproduction. So long as their metabolism is restrained by the antagonism of the host at viable limits the elaboration of noxious egesta is insufficient to provoke local inflammation, and reproduction only suffices to prevent extermination. In other words, under such conditions bacilli are saprophytes, living at the expense of the host but not being otherwise harmful. Indeed they may be beneficial despite some dissemination of organisms. Their noxious egesta, although not potent enough to provoke local reactions, supposedly arouse a measure of defensive systemic responses. There is no recognizable evidence of infection in this state, called latent tuberculosis. When the antagonism produced by the host is inadequate, the metabolism of the bacilli rises

above the limit of viability, and they become parasites. Elaboration of noxious egesta suffices to provoke local inflammation; bacilli reproduce more rapidly; both egesta and bacilli are so disseminated that obvious systemic responses occur, and other foci of infection are established.

Summary.—Tubercle bacilli, when they invade a body, enter an unfavorable environment.

They awaken more active antagonism by the actions of their noxious egesta that provoke local and systemic irritation and by the dissemination of bacilli.

In order to survive, the bacilli must maintain the rates of their metabolism at or above viable limits which fluctuate with the amount of antagonism offered by the host.

A majority of invaders succumb or are destroyed.

A proportion are able to maintain their metabolism at viable limits. They are saprophytes.

Saprophytes live at the expense of the host and produce latent tuberculosis.

Latent tuberculosis is harmless, possibly beneficial, so long as the bacilli are restrained in a state of saprophytism.

A proportion maintain the rates of their metabolism above viable limits. They are parasites.

Parasites produce focal and disseminated irritants and, so long as the rates of their metabolism are not reduced to or below viable limits, cause tuberculosis.

EVOLUTION

A majority of people are insusceptible to tuberculosis. The susceptibility of the minority is of divers grades and some organs and tissues are more liable to develop lesions than others. Since invasion of external surfaces and dissemination of bacilli, certainly to many, probably to all organs and tissues, occurs repeatedly, the insusceptibility of some persons and the relative insusceptibility of certain organs and tissues in the others are traceable to differences in the antagonism offered to the invaders.

Antagonism is the sum of the local and systemic responses to focal and disseminated irritants, which together produce resistance, defense and repair.

Resistance, defense and repair are produced by the activities of tissue cells adjacent to invading bacilli, supported, re-enforced and stimulated by the cellular and noncellular elements which emanate from the blood delivered to the structures invaded.

When resistance, which may be inherent or acquired, is adequate, the metabolism of invaders is restricted at or reduced below viable limits so promptly that manifestations of infection are undetectable. No

lesions, other than transient degenerations in contiguous cells, are provoked. Few bacilli are disseminated, and these are inactivated or destroyed with equal promptness wherever they are deposited.

Defense is aroused only if resistance is inadequate. Effective defense reduces the metabolism of bacilli to or below viable limits shortly but not until minimal lesions have developed. Noxious egesta and some bacilli have been disseminated. Manifestations of infection are slight but detectable. Meanwhile resistance is augmented rapidly, and the disseminated bacilli as well as those in the primary lesion are soon inactivated or destroyed. Less effective defense permits a longer duration of parasitic activities, the dissemination of more bacilli and noxious substances, and the development of larger primary and secondary lesions. Signs and symptoms of infection are unmistakable. Resistance is augmented gradually, and the disseminated bacilli are inactivated or destroyed, but not until some have produced manifest lesions in remote structures. Ineffective defense can but check the metabolism of parasites and thus retard the progressive development of lesions and the continued dissemination of noxious substances and parasites. Manifestations of infection increase in severity. Resistance is little augmented, and disseminated bacilli produce obvious lesions in several other structures, any one of which may be the cause of death instead of the initially preponderant lesion.

Repair begins with necrosis of tissue which results from destructive activities of parasites, and the injured tissue must be replaced if the disease is to be overcome. Cicatrization of minimal lesions impairs function immaterially. The scar is insufficient to be recognized intravitam and can escape detection post mortem. Moderately large lesions, if repair is effective, are completely healed but the cicatrix impairs function. Even though defense suffices to arrest progress and repair is efficacious, some of the larger lesions are unhealed. The contents of abscesses, the rigidity of their walls or the fixation of the walls to unyielding contiguous structures prevent the collapse and approximation of the inner surfaces of cavities requisite to obliteration and complete cicatrization. Such lesions are to be differentiated from the progressive types that occur when defense is defective and are incompletely cicatrized because repair is inadequate.

Resistance, defense and repair, although they act somewhat in sequence in one focus of invasion, are acting concertedly and constantly throughout the body because disseminated invaders are present in numerous foci and subsequent invasion through external surfaces is repeated. The powers of resistance, defense and repair are prone to fluctuate similarly in the same person but have unequal values in different persons.

Local responses of tissue cells to invading tubercle bacilli are those incidental to acute, subacute and chronic types of inflammation plus the formation of tubercles. The efficacy of these responses in providing antagonism varies materially in the divers organs and tissues of one person, but the efficacy of the responses of the same structures in divers persons differs immaterially unless they have been injured previously.

Systemic responses are aroused by the presence in the blood of the noxious egesta of tubercle bacilli and the products of tissue degeneration which together constitute the toxemia of tuberculosis. Although every cell in the body can be affected, discussion will be restricted to the cells that form blood corpuscles, to those that contribute other than catabolic products to the plasma and to the myocardium.

Mother cells of the various blood corpuscles are inherently more or less robust. Later, when the inevitable tuberculous infection occurs, they will have become stronger or weaker, and their capacities to work under protracted stress are dissimilar. They all respond sooner or later to irritation (toxemia) by increasing the production of their specific functions, namely, a production of corpuscles above the usual rates. (Some of them also elaborate antibodies.) These unusual activities are continued until the irritation ceases with recovery or until the metabolism of the mother cells is reduced by fatigue and intoxication. Underproduction of functions by the weakened cells then succeeds overproduction, and in consequence the host is handicapped in proportion to the significance of the contributions of the corresponding corpuscles to the maintenance of life and to the production of antagonism.

Similarly, the cells that produce the usual constituents of the plasma, for example, those of the liver and of other structures concerned in digestion, of the glands of internal secretion,[3] reticulo-endothelium, etc., are inherently more or less robust and more or less subject to fatigue and exhaustion. Similarly, too, if their metabolism is curtailed, their products are impaired quantitatively or qualitatively, and the untoward consequences are commensurate with the contributions of their usual products to survival and of their unusual products (antibodies) to antagonism.

The constituents of the blood are far more efficacious than the activities of tissue cells in producing antagonism to invading bacilli. Whatever structures are primarily invaded, untoward alterations in some constituent or constituents of the blood, revealed by repeated blood counts and estimations of sedimentation rates, are constantly present at the onset of tuberculosis. Thereafter the alterations parallel the course

3. Hyperthyroxinemia is constant in active tuberculosis, and the thyroid gland is prone to undergo degenerative changes in consequence of overwork and of toxemia.

of the disease. They become more favorable during improvement and not only disappear with recovery but are replaced with unusually favorable alterations which, if protracted, confer immunity. They grow progressively unfavorable as the disease progresses and commonly amount to cachexia as death approaches. Moreover, measures that improve the quality and increase the quantity of blood in circulation, particularly of that portion delivered to lesions, foster healing and other measures that remove lesions or promote their healing introduce improvement in the blood.

Those who are insusceptible to tuberculosis are able to make blood of proper quality in adequate quantity and to deliver it equably throughout their bodies under appropriate pressures. Their insusceptibility will endure so long as they retain those abilities. On the other hand, the susceptibility of the balance is proportionate to the deficits in those abilities, which are increased by age, unwholesome methods of living and disease. Hence, wholesome methods of living, viz., rest, recreation, avoidance of morbid emotions, ample well balanced diets, temperance, outdoor exercise, sunshine and energetic devotion to suitable occupations which favor formation and delivery of blood are invaluable agents in prophylaxis and in treatment.

Blood-forming units include the lymphatic and extralymphatic units; namely, the bone-marrow, intravascular and interstitial reticulo-endothelium, glands of internal secretion and all structures, such as the liver and digestive tract, which add to the plasma substances other than waste products. The component cells of the units are inherently more or less robust. Could an organism exist shielded from the unusual stresses imposed by hemorrhage, overexertion and disease, some of the cells would be incapacitated by senility before others, and this incapacity, even were there no other causes, would limit the life of the organism because all constituents of the blood are to some extent essential to longevity.

Inevitable unusual stresses hasten the incapacitation of the less virile blood-forming cells, and the consequent handicaps imposed on the organism are determined by the rôles played by the elements the cells contribute to the blood, to healthful existence, and to resisting pathogenic influences.

All constituents of the blood are more or less requisite to the provision of an effective antagonism to invading microbes. Antagonism to parasites that provoke acute processes or acute exacerbations of chronic processes is produced largely in the units within the bone-marrow and seldom provides lasting immunity. Antagonism to those arousing chronic processes is more from the lymph glandular units and, if effective, confers immunity. Certain parasites, e. g., *Streptococcus scarlatinae*, and sometimes the tubercle bacilli, provoke inflammations that are initially acute and, if the host survives, later become chronic. Antagonism emanates at first more from the units in the bone-marrow, later from those in the lymph glands which, if efficacious, confers immunity.[4]

4. Yates and Raine, in Lewis: Practice of Surgery, Hagerstown, Md., W. F. Prior Company, Inc., 1929. vol. 3, chapter 9.

Noxious egesta produced by invading tubercle bacilli are disseminated and produce what, in effect, is a toxemia. Every blood-forming structure in the body is thus irritated. If they are robust and the irritation suffices to provoke responses, they become unusually active and so continue until irritation ceases or they are progressively inactivated by fatigue, exhaustion, dehydration, malnutrition and intoxication. The consequences of overactivity are increments in the production of most of the corpuscles and of the usual constituents of the plasma, notably thyroxin, and the addition of protective substances which tend to reduce the metabolism of tubercle bacilli and to neutralize their noxious egesta.

The results of the earlier overactivities of the blood-forming structures and, if the disease progresses, of the subsequent lessened activities, are revealed by repeated examinations of the blood.

Early there is frequently a moderate polycythemia, later erythrocytopenia, and deficits in hemoglobin progress to cachexia.

Neutrophilia is present if the onset is acute, during acute exacerbations, in the terminal stages, and, as Medlar[5] has indicated, is seldom attributable to coincidental infection with pyogenic bacteria.

Eosinophilia, usually a late manifestation, occurs if there is a considerable necrosis of lymph gland tissue or of lymphocytes (Bunting).

Basophils are little affected.

An early actual or relative lymphocytosis is the rule; later, as the disease progresses, lymphopenia increases. If the larger immature lymphocytes are in excess, the lymphoblasts are overworked, and is a less favorable response than when small mature lymphocytes are produced.

A moderate monocytosis is quite constant and betokens the response of the reticulo-endothelium to irritation which is unwholesome when these cells are overproduced or, as sometimes happens, are underproduced.

The rate of production of both lymphocytes and monocytes is indicative of the nature of the responses of the lymph gland units throughout the body and of the extralymphatic reticulo-endothelium which contribute the larger portion of the antagonism to tubercle bacilli. During intervals of health the number of lymphocytes and of monocytes produced bear a fairly constant ratio. Cunningham and Tompkins[5a] have showed that this may be expressed graphically and also numerically by dividing the number of monocytes by the number of lymphocytes. The normal quotient is 0.3. If this observation be applied to patients suffering from tuberculosis, quotients in excess of 0.3 are less favorable and quotients below 0.3 are more favorable indexes. Fluctuations in these quotients occur during positive and negative phases of the disease and are of little significance if estimated from one count. If repeated counts are made and the ratios are quite constantly above 0.3 or below it, this is a factor in establishing a less favorable or a more favorable prognosis.

Protective substances are the most significant defensive constituent of the plasma. Their production seems to be nearly equivalent to the formation of the other constituents, and they contribute essentially to antagonism. The quality and quantity of protective substances in the blood cannot be determined directly, but they can be estimated indirectly since they vary inversely with rates of sedimentation. Early in the evolution of tuberculosis, sedimentation rates are abnormally rapid, less rapid if the antagonism is higher. If the disease progresses, they become correspondingly more rapid, particularly during exacerbations. Con-

5. Medlar: Am. J. M. Sc. **173**:824, 1927.

5a. Cunningham and Tompkins: Am. Rev. Tuberc. **17**:204, 1928.

trarily, if there is regression of the disease, the rates of sedimentation are slower; with and after recovery they are slower than normal.

Increments in basal metabolism during the active phases of tuberculosis and the degenerations noted post mortem in the thyroid glands of many patients who succumb to the disease indicate at once the constancy of hyperthyroxinemia during the more active phases of the malady and the importance of the contribution of the thyroid gland to antagonism.

The first step in the pathogenesis of tuberculosis is penetration of an external surface of the body, which occurs more often in the mucosa of the digestive tract.

All varieties of tuberculosis are systemic infections which develop because deficits in the blood permit invading bacilli to maintain their metabolism above viable limits. They differ solely in the location of predominant lesions, i. e., in skin, bone, central nervous system, lungs, lymph glands, spleen, digestive and genito-urinary tracts, serous cavities, fasciae, etc.

Except the delivery of bacilli to lymph glands in the lymph, to the liver in the blood of the portal circulation, pulmonary infections and those due to extension as from tuberculous tubes and intestines to peritoneum, all but surface structures are invaded by bacilli transported in the arterial blood of the systemic circulation, and liver, lungs and lymph glands may be thus infected. They are deposited on the endothelium of arterioles and capillaries which forms the nutritional surface of the body.

The number of bacilli present in the systemic arterial blood at any time is only large during the interval preceding the development of generalized miliary tuberculosis. The total number present throughout a lifetime is so large, because of repeated invasions of the body, that bacilli are deposited at one time or another on the nutritional surface of every structure and many times on some of them.

At the time of invasion of organs and tissues and during pathogenesis the quality of blood they receive is the same, though the quantity of blood and the extent of their nutritional surfaces vary greatly. Why then is tuberculosis relatively uncommon in some structures having a plentiful blood supply (brain, muscle, thyroid) and relatively common in others (kidney, liver, spleen)? Why is fascia lata so seldom affected?

Structure and function differ widely. Some structures are the more often subject to physical injuries, others to injuries inflicted by disease. It is unlikely that the nutritional surfaces are equally penetrable. Although the responses of tissue cells are less effective than the elements derived from the blood, nevertheless their contributions to antagonism are not only significant but also dissimilar and peculiar.

Organs that abstract chiefly water, salts and nourishment from the blood (thyroid, brain, muscle) are less prone to invasion than those

concerned in digestive, eliminative and defensive processes (liver, kidney, spleen), which withdraw additional substances. Peculiarities are exemplified in bones and lymph glands which are particularly susceptible to tubercle bacilli of the bovine type and quite as insusceptible to those of the avian type. Fibrous tissue, whether normal or cicatricial, is barren soil for bacilli. Hence the infrequency of fascial tuberculosis. The increased susceptibility of structures that have suffered previous injury which has resulted in some scarring is not attributable to the presence of fibrous tissue per se but to the reduction in blood supply.

Longevity depends on myocardial integrity. Myocardial weakness is revealed particularly by prolonged stress. Heart muscle is peculiarly vulnerable to the noxious egesta of tubercle bacilli and to the products of tissue degeneration they provoke.

Summary.—Inherent and acquired susceptibility and insusceptibility and the grades of susceptibility and insusceptibility are proportionate to lesser or greater degrees of antagonism offered by hosts to bacilli that have become invaders by having penetrated an external surface of their bodies.

Antagonism is the product of local and systemic responses to focal and disseminated irritations which together constitute resistance, defense and repair.

Adequate resistance confers insusceptibility. Invading bacilli are suppressed so promptly that there are no evidences of infection and the slightly degenerative lesions are evanescent.

Inadequate resistance and effective defense and repair that develop promptly lead to an early suppression of bacilli, but there are manifestations of infection though the lesions are minimal and the cicatrices too slight to impair function.

Less effective defense permits primary lesions to become larger before bacilli are suppressed; secondary lesions are often recognizable. Evidences of infection are unmistakable; healing usually occurs but functions are impaired. Sometimes healing is prevented by interference with collapse of abscesses even though defense and repair are potent. Such lesions are to be distinguished from lesions that progress because defense and repair are impotent by means subsequently mentioned.

Ineffective defense and repair fail to suppress bacilli; lesions slowly or rapidly progressive, manifestations of infection, and the outcome are unmistakable.

Resistance, defense and repair fluctuate throughout the course of the disease more or less equally.

All the contributions of local and systemic responses to antagonism are significant but those of the blood are the most effective.

Local responses of the same structures in different persons are equally effective unless there has been previous injury.

The efficacy of systemic responses is dependent principally on the stamina of the units that form blood corpuscles and plasma.

Here again the contributions of all the hematopoietic units to antagonism are significant but those of the plasma (antibodies) are most effective.

As the blood-forming cells weaken, the greater the susceptibility of the host and the less the chances of recovery. This is revealed by repeated blood counts and estimations of sedimentation rates which are found to fluctuate with the course of the disease.

All forms of tuberculosis are systemic infections. All begin with penetration of an external surface, and of these surfaces the mucosa of the digestive tract is the principal offender.

All forms of tuberculosis can be caused by penetration of nutritional surfaces (systemic capillaries) by bacilli deposited on the endothelium from systemic arterial blood although the lymph glands, liver and lungs have other sources of contamination, and the surfaces are open to direct invasion.

The liability of various structures to infection depends on their blood supply, whether they do or do not abstract more than water, salts and food from the blood, on the efficacy of the responses of their parenchymal cells in producing antagonism, and on the stamina of those cells. Proof of the effectiveness and of the peculiarity of the responses of parenchymal cells is found in the susceptibility or insusceptibility of divers structures to human, bovine and avian bacilli.

The myocardium is a dominant factor in combating tuberculosis and is particularly sensitive to the noxious egesta of tubercle bacilli.

PREVENTION

Restriction of the deposition of human, bovine and avian bacilli on external body surfaces would reduce the incidence of the disease materially as proved by eliminating tuberculous cattle from dairy herds. So long as bacilli of the human type are present in the air they will be deposited on bronchial mucosa and the skin and directly or indirectly on ingesta. Bovine bacilli are still present in dairy products. Avian bacilli are contained in the eggs of tuberculous hens which are said to be numerous, and these bacteria are not always destroyed by cooking.

More attention given to personal cleanliness, to the selection, preparation and serving of food, exclusion of the tuberculous from those who handle, prepare and serve food, elimination of tuberculous chickens, prevention of the marketing of milk, butter and cheese of questionable origin and handling are needed to restrict contamination.

This aspect of prophylaxis is not immediately attainable, so that the other aspect, the institution of wholesome methods of living which develop and conserve the stamina of the entire circulatory apparatus, the structures concerned in the formation, rectification and delivery of blood, must be the chief reliance.[6]

Further preventive measures should be more generally employed because it is impossible as yet to determine existing grades of susceptibility or insusceptibility and to estimate how long they may endure. Penetration of the cutaneous surface is infrequent, and of the mucosa of the genito-urinary tract rare, but penetration of the mucosa of the digestive tract not only is frequent but is the common origin of tuberculosis. Bacilli are more likely to penetrate or to be transported in phagocytes through lesions than intact surfaces, and more when contact is prolonged than when it is brief.

Repair and extraction of decayed teeth, the removal of adenoids and of unwholesome tonsils, and the correction of chronic dermatitis are desirable even though glandular tuberculosis has all but disappeared. If it be recalled that bacilli of the human type are not only ubiquitous but are frequent invaders which can be disseminated through the blood or through the lymph without provoking tuberculous lymphadenitis and later reach the blood, then the wisdom of eradicating portals of entry from external surfaces becomes indisputable. By the same token, correction of constipation in persons of the phthisical habitus is necessary, sometimes even when this demands resection of inert intestinal segments.[7] The indications are as obvious as they are disregarded. First, to eliminate anorexia resulting from indigestion due to stasis; second, to eliminate the toxemia of constipation and thus to improve nutrition; and third, to reduce the frequency of penetration by bacteria of the mucosa and lymph follicles in the affected loops (often terminal ileum and proximal colon), and to obviate the formation of superficial mucous

6. Grades of insusceptibility are commensurate with the strength and endurance of the circulatory apparatus, particularly with the stamina of the blood-forming units, and more especially the lymphoblasts and reticulo-endothelium. The grades of susceptibility are proportionate to the frailties in these structures. There is no distinct demarcation. Lesser grades merge in a common zone wherein there is at one time a modicum of insusceptibility, and at other times, of susceptibility. Higher grades of insusceptibility endure throughout life, however it be prolonged. Lesser grades are dissipated by accidents, disease, unwholesome living and senility. Higher grades of susceptibility can be reduced by proper living but cannot be overcome. Persons so handicapped are destined to die of tuberculosis unless they succumb to another ailment. Their reproduction should be discouraged because inherent frailties are irremediable. Lesser grades of susceptibility can be curtailed, even replaced by insusceptibility, if living is well ordered, and accidents and diseases are escaped.

7. Yates, Raine and Stevens: Am. Surg. **90**:517, 1929.

ulcers by the prolonged pressure of intestinal contents which favor bacterial invasion.

Summary.—The first and most important step in prevention of tuberculosis is to eliminate human, bovine and avian tubercle bacilli from ingesta. The means are to prevent human bacilli from getting into the air, to stop the sale of milk, butter and cheese containing or likely to contain bovine or human bacilli, and to destroy tuberculous chickens. The second and next most important step is to introduce wholesome living more generally. The third is to minimize the likelihood of penetration of body surfaces by bacilli, more particularly the teeth, tonsils, mucosa and lymph follicles of the digestive tract.

TREATMENT

Treatment consists in assisting patients to develop and to maintain the antagonism that confers insusceptibility, or, if that is impossible, to acquire the least grade of susceptibility. Prerequisite to treatment is a recognition of the existence, the location and progress of the disease and a determination of the existing powers to make and to deliver blood.[8] Diagnosis and prognosis establish what means, if any, should be employed to augment the defensive capacity of the host, to reduce the offensive power of the bacilli, to conserve the energies of the host and to obviate recrudescences.

Reducing Offense.—Search will sometimes reveal the portal of entry, usually other possible portals, and, when feasible, all should be eradicated because of the probability of reinfection. Should the regional lymph glands contain the predominant lesions or serious lesions that assure dissemination, their radical extirpation is indicated if it can be tolerated. Predominant lesions, wherever located, are harmful because of the local destruction and the dissemination of noxious products and bacilli. Dissemination can be restricted by curtailing the activities of the affected structure. During acute phases complete immobilization is necessary although it induces the atrophy of nonuse in tissue cells, reduces the amount of blood delivered, and thus minimizes antagonism.

8. Deficiencies in the blood develop before tuberculosis can be established. Consequently all persons suffering from tuberculosis, save those well advanced toward recovery, have blood deficits. It is impossible in the earlier phases of the disease to determine promptly which patients have a circulatory apparatus of so little stamina that they will become cachectic despite assistance and therefore cannot recover. Patients seen in the later phases have or have not lost the stamina of their circulatory apparatus. One examination of their blood will not be decisive. Blood counts and estimations of sedimentation rates repeated at intervals while patients are being given appropriate care will demonstrate which have lost hematopoietic capacity and with it the chance to recover. Prolongation of the lives of those hopelessly ill is usually cruel.

As soon as safety permits, gradually increasing activation is indicated, as it assures the utmost recovery of function. If the structure can be sacrificed without jeopardizing life or imposing undue permanent disability (fallopian tubes, testes, ribs, sternum, fingers, toes, etc.) or if such sacrifice is or becomes requisite to recovery (kidney, segments of intestine, extremities, etc.), prompt removal is wisest. Sometimes the predominant lesion demands intervention because of its collateral effect (pressure on the cord by pachymeningitis incidental to spinal caries) and sometimes a subsidiary lesion must be removed (amputation of tuberculous extremities) to permit healing of a predominant lesion (lungs). The proper treatment of abscesses may be perplexing, i. e., whether to aspirate, to institute drainage or to do nothing.

It is easy to recognize the need for operations when they have become imperative and may then be futile. The difficulties are to interpret early indications and to have the courage to act on them or to persuade patients to consent. Estimating the capacity of patients to make blood furnishes more dependable information than any other single factor, though all must be considered, especially the patient's morale.

Augmenting Antagonism.—The first requirement is to improve the quality of blood in circulation, and, if necessary, to restore its volume; the second is to increase the quantity delivered to lesions. Rest is essential, but it can be overdone as well as underdone. Air is not so fresh indoors as outdoors. Ample protection against cold is needed to limit heat production. Patients so protected should be kept on porches most of the time, day and night. Sunshine increases basal metabolism. It stimulates blood production if exposures are restricted to individual needs. Overexposures are more harmful than none. They cause fatigue, curtail the production of both cellular and noncellular elements of the blood, and may suffice to introduce an exacerbation. The benefits of the various artificial lights are greater if the lights imitate sunshine rather than produce part of the spectrum and if exposures are suitably regulated. Diets should provide fuel enough to satisfy current expenditures of energy and to provide for the storage of potential energy but not to overfatten. The requirements in water, salts, vitamins and foods are simple and should be met. Too little water is taken. Provision of salts, particularly iodine, is insufficient. Foodstuffs, perhaps of good quality, are ruined by poor preparation and unattractive service. The tendency to overeating or overfeeding is general. Excess fat is a liability. The digestive tract, often the site of primary invasion and constantly liable to infection, should not be overworked any more than heart muscle. Constipation is a menace.

Blood deficits that are serious when treatment begins or that do not disappear thereafter indicate that blood-forming structures are fatigued

or exhausted. If fatigued, they can be rested and allowed to recover most certainly by repeated transfusions of unmodified blood. Sometimes sugar and salt should be given intravenously to combat dehydration and malnutrition. Transfusions, dextrose and salt given intravenously are most useful in preparing patients for operation, enabling them to tolerate the stresses and expediting recovery. Giving drugs by mouth is usually futile and occasionally is harmful. If the blood-forming units are exhausted, transfusions may only prolong life for limited intervals.

Helping patients to keep their morale high is a major part of treatment. If they need no active measures, they usually know it. If they are in need of more than pacifistic measures, there should be no delay. If they are irremediably affected, telling the truth is sometimes better than continued deception. Amusement, recreation and occupation are as necessary for the mind as suitable diets are for the body.

Exercise is needed to increase delivery of blood, to develop and maintain the robustness of cells and to prevent deterioration. Mental and physical exercise is particularly indicated in combating chronic systemic diseases like tuberculosis.

Conservation of Energy.—The conservation of energy consists not only in restricting the expenditures of energy within limits of necessity but also in promoting the storage of reserve energy to provide a margin of safety. The hypermetabolism that produces fever necessitates compensatory rest. Lower grades of fever permit of some exertion. Afebrile states indicate exercise, gradually increased, but always within the limits of undue fatigue. Thus alone may the warehouses that store sources of reserve energy be enlarged and filled. Undue caution in reactivation prolongs convalescence and sometimes induces incapacitating temerity or permanent inertia.

Prevention of Recrudescences or Recurrences.—Development of the disease proves deficient antagonism. However complete the apparent immediate recovery, some of the bacilli inactivated to transient saprophytism probably persist in the body, and, even if they do not, reinvasion is certain. It is impossible to differentiate temporarily increased resistance from permanent immunity. It is safest to assume that the immediate insusceptibility is low and likely to be dissipated, possibly years hence. Wholesome living, a suitable occupation, and the avoidance of exposure to reinfection should be continued throughout life.

PULMONARY TUBERCULOSIS

Lungs are remarkably resistant to invading bacteria; their defensive capacity is exceptionally high, and, when unhandicapped, they are able to effect well-nigh scarless healing of fairly large lesions. The causes

of their being so commonly involved in all tuberculous procsses and the measures that will promote recovery from pulmonary tuberculosis are revealed in the peculiarities of their structure and function.

The significant structural characteristic is the unique disproportion between the vast total expanse of the five lung surfaces and the limited bulk of parenchyma. The external or ventilating surface is formed by the bronchial mucosa and the cells lining the 404,000,000 alveoli. Aeby has estimated the area of the alveolar cells in an adult at the end of inspiration to be 79 square meters during intervals of rest and 129 square meters when activities are highest. This is about 40 to 70 times the average skin surface (1.8 square meters) without considering the expanse of bronchial mucosa and is from 75 to 125 times as large as the surface of the intestinal mucosa (1 square meter?). The internal or aerating surface, formed by the endothelium of the capillaries of the lesser circuit, approximately equals the external surface during inspiration and expiration, whether quiet or labored. Mesothelium forms the pleural surface, lymphatic endothelium the drainage surface, and hemangio-endothelium of the capillaries of the greater circuit the nutritional surface. The bronchial vessels are under systemic vasomotor control, which is absent in the pulmonary vessels. Lying beneath, on and between the pulmonary surfaces and surrounding the blood and lymph vessels is the restricted parenchyma which is both supporting and contractile.

The functions of the lung are external respiration, filtration of inspired air, filtration of blood delivered through the pulmonary arteries, elaboration of antibodies and digestion of fats and carbohydrates.

External respiration or aeration of blood is requisite not only to survival but to activity. Moderate impairment of its effectiveness restricts the production of functions needed for exertion and to combat disease. Immoderate impairment limits the production of functions to those required to support inactive life or reduces them below the limits of viability.

Aeration continues if a balance is maintained between the volume of continuously ventilated alveolar air and the volume of blood driven at normal velocity through the capillaries of the pulmonary circuit. Either of these factors may vary widely and abruptly under usual conditions, yet, because of the automatic action of the air-cell-capillary mechanism discovered by Dunham, their coordination is assured provided the heart remains competent and the lung retains its elasticity. The mechanism is as promptly effective under unusual conditions. The interrelationships that obtain in human beings are easily summarized.

If air is prevented from reaching alveoli by obstruction of a bronchus, there is almost immediate atelectasis, and a corresponding

collapse of the pulmonary capillaries. The blood normally destined to flow through the collapsed vessels is diverted to adjacent unaffected capillaries which are overfilled. This causes a compensatory emphysema, and the excess blood is thereby aerated. Should a branch of the pulmonary artery be occluded, the capillaries distal to the occlusion collapse, and atelectasis is a prompt consequence. Again blood is diverted, produces a compensatory emphysema and assures aeration. Other abnormal states produce similar adjustments. Consequences are similar if an entire lung is affected. Reduction in intrapleural negative pressures which produce successively deflation and collapse or a production of positive pressures that impose compression of the homolateral lung causes diversion of blood to the other lung and compensatory emphysema within it.

Prompt and proportionate responses to usual and unusual influences which produce the extraordinary adaptability of the lung likewise make it vulnerable. Atelectasis following deprivation of air or of blood from the pulmonary artery, if prolonged, becomes permanent because of the contractility of the parenchyma, vessels and bronchi. Similarly, protracted collapse and compression which check respiratory movements prevent recovery of elasticity. Deflation on the contrary permits some respiratory movements, preserves pulmonary elasticity, and full inflation occurs when normal intrapleural negative pressures are reestablished. Interruption of the flow of blood through the bronchial arteries which are end-vessels causes necrosis of the lung structure affected, including its overlying pleura. Blood in the bronchial arteries supplies not only nutrition to the entire lung but also the cellular and noncellular elements that contribute the major part of resistance, defense and repair.

The effects of parenchymal lesions which restrict blood, lymph and air conduction or impair elasticity are similar to reductions in the volume of blood in circulation, in its oxygen-carrying power or in its pressures because of myocardial subcompetence. All interference with external respiration and the extent of the interference is commensurate with reductions in vital capacity and breath-holding time.

Filtration of the inspired air removes foreign bodies and noxious gases. Dust and bacteria, some of them pathogenic, are present in the air. The amount of dust and the number of bacteria inhaled are far larger than are exhaled, the balance being deposited on the walls of air passages. The amount of dust and the number of bacteria deposited within the lung diminish with the distance from the origin of bronchi. If the mucosa is intact and the passage of air is unobstructed, the ultimate bronchioles and alveoli are uncontaminated. Abstraction of irritating gases from air is less effective. The chief defense is limiting inspiration and promoting expulsion.

Filtration of blood includes the removal of foreign bodies (inert particles, bacteria and dead or dying cells) and the abstraction of noxious products. This form of physical and chemical filtration of the lymph is effected by lymph glands, of the portal blood by the liver and of the arterial blood in the systemic circulation to some extent by all structures, including the lungs, but mainly by kidneys, spleen, liver and the intestinal tract. All noxious products and foreign bodies in the systemic arterial blood, in the portal blood and in the lymph that escape the filtration just outlined and all that enter the systemic venous blood are delivered to the lungs in the blood in the pulmonary arteries unless there is a patent foramen ovale. Lymph from the receptaculum chyli is the chief source of bacterial contamination, particularly during periods of active intestinal digestion when some bacteria are present and a part of them are pathogenic. Abstraction of noxious substances from the blood by the aerating surface is prompt if they are volatile (alcohol, ether, acetone, etc.) and probably also if they are not. The efficacy of the external and aerating surfaces of the lung as filters of foreign bodies is proved by pneumonoconiosis, the black spit of those inhaling coal dust, the failure of insufflation to drive bacteria into bronchioles and alveoli, the common presence of bacteria in the lymph and the relative infrequency of bacteria in the arterial blood as compared with venous blood in the systemic circulation.

Fried [9] indicated at the last meeting of this association that antibodies were produced by the endothelium of the pulmonary capillaries, the cells lining the alveoli and certain cells within the parenchyma, also that these cells could digest fats and carbohydrates.

INCEPTION

The first requirement is penetration of one of the five surfaces of the lung by tubercle bacilli. The second is that the bacilli shall invade the parenchyma, and the third that the antagonism offered by the host shall be insufficient to inactivate or to destroy the invaders by restricting the rates of their metabolism to viable limits or by reducing the rates below those limits. The surfaces will be considered separately.

External Surface.—Inert foreign bodies, bacteria and probably tubercle bacilli [10] are constantly present on the mucosa of bronchi and larger bronchioles that have submucosa, rarely, if ever, under normal conditions on the surface of the ultimate bronchioles and the alveoli which have none. Penetration of bronchial mucous membrane by bacteria occurs as has already been described for other surfaces. Bacilli, under pressure exerted by secretions or exudates, pass into, through or

9. Fried, B. M.: Defensive and Metabolic Apparatus of Lungs; Lungs and Macrophage System, Arch. Path. **6**:1008 (Dec.) 1928.

10. Opie: Am. Rev. Tuberc. **14**:347, 1926.

between cells of an intact mucosa, through lesions of the mucosa or are transported within wandering phagocytes.[11]

A portion are retained in the mucosa or submucosa. Those able to maintain parasitic activities provoke lesions (bronchitis and peribronchitis); the balance are inactivated to saprophytism or are destroyed. The other portion of the invaders penetrate the walls of capillaries or are carried through them in phagocytes and are transported in the blood of the bronchial vein or in the lymph.

Bacilli transported in the blood in the bronchial veins are returned in the blood in the pulmonary artery. Those transported in the lymph pass to the peribronchial glands in which the majority are removed. According as they are active or are inactivated they do or do not cause tuberculous lymphadenitis. Lymphadenitis does or does not obstruct the intraglandular sinuses and does or does not result in destruction of the gland capsule with production of active periadenitis. If the intraglandular sinuses are obstructed, the lymph is compelled to flow through collateral channels, some of which pass through lymph follicles within the parenchyma of the lung. Thus bacilli are deposited in the intrapulmonary lymph follicles and the consequences are the same as if they are deposited in peribronchial lymph glands. If folliculitis develops, it may progress to an active tuberculous perifolliculitis.

Periadenitis and perifolliculitis, tuberculous bronchitis and peribronchitis may result in pulmonary tuberculosis by direct extension. Otherwise there is little likelihood that the parenchyma of the lung will become directly involved from penetration of its external surface. Indirect parenchymatous involvement by bacilli transported in the lymph is probably infrequent at onset, whereas this form of involvement by bacilli transported in the blood in the pulmonary artery is common.

Available evidence indicates that virulent tubercle bacilli are commonly, if not constantly, present on the bronchial mucosa proximal to the ultimate bronchioles and that this portion of the external surface of the lung is repeatedly penetrated by the bacilli. After penetration

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11. The black spit of those breathing air containing coal dust proves that foreign bodies are expelled with bronchial secretions. Tubercle bacilli are seldom found in the sputum of persons who have not active pulmonary tuberculosis, and not always when they have the disease. Pneumonoconiosis proves that not all foreign bodies present on the external surface are expelled with secretions, and the lesions suggest that the lymphatics are active in removing such as pass through this surface. Insufflation of bacteria into bronchi does not carry them to the ultimate bronchioles and alveoli. Causing susceptible animals to breathe air containing tubercle bacilli does not invariably provoke pulmonary tuberculosis, but this is almost a constant consequence of intravenous injections thereof. Presumably the number of tubercle bacilli present on the external surface of the lung is not large enough to be expelled as is coal dust, and their presence is not of necessity a menace.

the majority of the invading bacilli enter or are carried into the lymphatics. Though they frequently cause peribronchial tuberculous lymphadenitis and perhaps intrapulmonary tuberculous lymph folliculitis, these lesions are infrequently the origin of parenchymal lesions. On the other hand, the minority of the invaders carried in the blood in the bronchial veins are returned to the lung within the pulmonary artery and are often the cause of the disease.

Aerating Surface.—The number of bacilli that penetrate the external surfaces of the body at one time is small, but this occurs so often that the aggregate is large. A proportion of the invaders eventually are transported in the blood in the pulmonary artery and the majority of them are deposited on the aerating surface, relatively few passing on to be disseminated in the arterial blood of the systemic circuit. The bacilli present on and within the endothelial cells of the pulmonary capillaries, perhaps those within phagocytes in the parenchyma, explain in part why Opie found virulent organisms in bits of lung wherever they were excised.

Penetration of the aerating surface by organisms deposited on it is the most certain origin of pulmonary tuberculosis and the commonest. The sources of the bacilli are from penetration of an external surface of the body and from extrapulmonary tuberculous lesions. Penetration of skin and of the mucosa of the genito-urinary tract is infrequent; of the external surface of the lung is repeated, and of the mucosa of the digestive tract is frequently repeated. These facts explain why digestive disturbances frequently occur at or before the onset of pulmonary tuberculosis and why pulmonary and extrapulmonary lesions are often coexistent.

Nutritional Surface.—Bacilli must be present in the blood in the bronchial artery if pulmonary phthisis is to arise from invasion subsequent to penetration of the nutritional surface. In order to gain the systemic arterial blood, bacteria must pass through the pulmonary circuit unless there is an open foramen ovale. The majority of organisms are deposited from the blood in the pulmonary artery on the aerating surface, so that the inception of pulmonary tuberculosis from bacilli deposited on the nutritional surface is exceptional save in generalized miliary tuberculosis.

Bacilli are disseminated in the systemic arterial blood and sometimes without provoking pulmonary lesions; for example, to the bones and to the central nervous system. It is important to recall that in pulmonary tuberculosis, even in its incipiency, bacilli are disseminated through the systemic arterial blood and do cause extrapulmonary lesions, notably renal.[12]

12. Medlar: Am. J. Path. **2**:401, 1926.

Drainage Surface.—The drainage surface is large in proportion to the bulk of the parenchyma. Lymph flows from the periphery toward the hilum in the peribronchial and parenchymal vessels which intercommunicate and is delivered into the afferent sinuses of the tracheal glands. Lymph gland units are placed at intervals along the lymph vessels. The consequence of removal of bacilli from the lymph stream has already been outlined in the discussion of invasion through the external surface. One other detail is noteworthy. If the sinuses within a tracheal gland become obstructed by tuberculous adenitis, the outflow of lymph through these channels is prevented. Lymph then flows from the hilum toward the periphery until it finds egress through unobstructed afferent channels. In this way there may be a retrograde infection of glands, a subsequent periadenitis with extension to the parenchyma. Seldom would this occur in the establishment of a primary pulmonary lesion.

Atypical lymph vessels develop in adhesions between visceral and parietal pleurae. Thus the glands in the inferior cervical region are commonly involved if there are apical lesions and adhesions. Contrarily, tuberculosis of the cervical glands might extend thus to involve the lung.

Pleural Surface.—The initial intrathoracic tuberculous lesion might be in the pleura caused by bacilli delivered through the bronchial artery or deposited on the visceral pleura from lesions in the thoracic cage or adjacent glands. The usual sequence is extension from a subpleural parenchymatous focus.

Summary.—Pulmonary tuberculosis develops only in susceptible hosts after penetration of one of the five surfaces of the lung by bacilli that had entered the body through one of its external surfaces that may or may not have produced extrathoracic lesions.

Pulmonary tuberculosis is the common form of the disease or the common concomitant of other forms not because the parenchyma is unable, if normal, to contribute affectively to antagonism but because bacilli are deposited at brief intervals on its aerating surface, and the lung is subject to repeated injuries that vitiate its responses to subsequent irritations.

The chief sources of bacilli are penetration of the gastro-intestinal mucosa and of the bronchial mucosa proximal to the ultimate bronchioles, and extrathoracic foci of tuberculosis.

The chief avenue of infection is penetration of the aerating surface by bacilli deposited on it from the blood in the pulmonary artery.

EVOLUTION

After the inception of lesions in the lung, which occurs only in susceptible hosts, their subsequent evolution is quite the same as in other structures, and the course varies with the existing degree of suscepti-

bility. The natural contributions of the activities of its component cells to resistance, defense and repair are uncommonly effective, the blood supply is large, and the lung is highly adaptable. On the other hand, lungs are very sensitive to alterations in tension, even to the slight changes caused by incipient lesions because the volume of parenchyma is so restricted. Direct and indirect consequences of the alterations are reductions in the amount of blood delivered through branches of the bronchial artery which furnishes most of the nutrition and contributes mainly to antagonism.

Lesions in least susceptible hosts seldom exceed miliary tubercles, and were they not frequently calcified would be undetectable. They do not impair function. Recovery of these patients cannot be prevented by maltreatment, but it can be expedited by favorable treatment. As the lesions develop in moderately susceptible hosts they create increasing tension which interferes with the passage of air, compresses the pulmonary capillaries and terminates in atelectasis in the portion affected. Atelectasis reduces the supply of bronchial arterial blood. Atelectasis also promotes fibrosis, and this is hastened by the inflammation. Fibrosis is favorable to healing but unfavorable to resistance and defense because the systemic blood supply is curtailed. Unless the bacilli are promptly inactivated, a vicious cycle is inaugurated. Interference with the delivery of blood permits lesions to extend, and the larger the lesion, the more the restriction of blood supply and the greater the liability to caseation. A majority of these patients will recover if given only proper expectant care, but the duration of their illness and the extent of their lesions is avoidably great. Some who develop larger cavities because of untoward local conditions will only recover or be enabled to arrest the progress of their disease if intrathoracic tensions are so altered by operations as to assure collapse of the cavities.

Lesions develop in immoderately susceptible hosts in three ways: 1. When the offense-defense ratio is low, the irritation is slight and the responses are sluggish. A gradually progressing fibrosis results which cannot be materially controlled. 2. When the offense-defense ratio is high, lesions develop and extend more rapidly, caseation is pronounced and multiple cavities are formed. Drainage is inadequate, toxemia is higher and more bacilli are disseminated. The lives of a few of these patients can be prolonged if their cavities are collapsed, and some can be made more comfortable. The majority are too ill to withstand operation, or, if they survive, are unable to effect enough repair to justify the discomforts and danger. 3. When the offense-defense ratio is very high, acute pneumonic phthisis develops and is seldom amenable to treatment.

Invaluable clinical lessons can be learned from the progress of lesions in the lung. At onset all lesions are incipient, and, excluding the pneu-

monic processes, it may be impossible promptly to differentiate grades of susceptibility. Safety demands that each patient be regarded as less competent to develop antagonism than observations may indicate. Whatever measures will promote recovery without imposing undue handicaps (e.g., permanent reduction in vital capacity) should be utilized at once, not after waiting to observe progress. Similarly when patients are seen after onset, the measures that will retard progress without adding materially to handicaps should be employed before the possibility of recovery or even of arrest is forfeited provided that has not already been lost.

The stresses imposed by the disease affect the whole body, more particularly the circulatory apparatus. Blood formation, originally inadequate, is apt to be further impaired by fatigue and intoxication of all hematopoietic structures, especially the weaker units, the very ones that because of their incompetence the disease was established. Heart muscle is similarly affected and myocardial weakness is often more serious than the pulmonary lesions. Vital capacity is reduced and restricts the production of the excess energy required to provide defense.

Every new lesion in the lung or pleura reduces the elaboration of antibodies, increases dissemination of noxious substances and bacilli even more than the inception and progress of other lesions. The greater the number of bacilli disseminated, the more certain the development of multiple extrapulmonary lesions. All foci of pulmonary disease raise peripheral intravascular resistance which increases cardiac burdens. In brief, the earlier the disease, the more hopeful the outlook, and the more inexcusable is procrastination in employing aggressive therapy.

Summary.—Evolution of pulmonary tuberculosis is determined by the nature and extent of the deficits in constituents of the blood, whether the deficits result from fatigue or exhaustion of the structures that form those constituents, and by alterations in intraparenchymal tension.

When the disease is in its incipiency, it is seldom possible to determine at once the capacities of patients to develop the antagonism needed for recovery or to arrest progress.

Safety demands that each patient be regarded as less than apparently competent and be treated as promptly and as aggressively as conditions warrant.

None would be injured if this plan were followed. The recovery of those of least susceptibility would be expedited, and of those of moderate susceptibility would be assured with the least immediate and ultimate disability. The lives of those of immoderate susceptibility would be prolonged.

When the disease is moderately advanced, it is usually possible to determine within a few weeks, as will be described later, whether or not recovery or arrest is attainable by some form of active intervention. If

the disease is immoderately advanced, the objectives are to prolong active lives and to restrict discomfort, not to protract existence.

PREVENTION AND TREATMENT

Prevention.—The chief sources of contamination are bacilli in air and ingesta. The more serious portals of entry are in the mucosa of intestines, bronchi and larger bronchioles, tonsils and carious teeth.

At present the number of bacilli in air and ingesta cannot be reduced although the means are obvious. Affected tonsils can be removed and carious teeth corrected. Wholesome living will afford all possible protection against bronchial and intestinal lesions. Some persons are unfortunate heirs to weak intestinal muscles which are often more pronounced in the proximal and terminal segments of the colon. Weakness causes stasis, digestive distresses and malnutrition. Stasis favors penetration of the intestinal mucosa by bacteria and absorption of noxious substances. Malnutrition vitiates antagonism. If constipation cannot be otherwise relieved, operations are sometimes indicated. Justification for care in correcting gastro-intestinal malfunctions, even though it entails serious operations, is found in the frequence of digestive disturbances preceding inception of pulmonary lesions, in the common development of intestinal tuberculosis in those suffering from pulmonary phthisis and in the knowledge that a large number, if not the majority, of tuberculous infections of the lungs are caused by bacilli that invaded the intestinal mucosa. Suitable hygiene will always be the effective means to conserve and to augment insusceptibility and to reduce the grades of susceptibility.

Treatment.—Pulmonary tuberculosis is a systemic infection with tubercle bacilli wherein the predominant lesions are in the lungs. It begins because the responses of tissue cells adjacent to invading bacilli are supplemented inadequately by the cellular and noncellular constituents of the blood delivered through the bronchial artery. Although the efficacy of tissue cell responses may be impaired through previous injury, deficits in some of the constituents of the blood are the constant and determining contributing factor in the origin and throughout the progress of the disease. Recovery occurs spontaneously if the structures which produced the constituents initially deficient are sufficiently robust to respond to the added stress of toxemia by overproducing instead of underproducing those constituents, if the lesions in the lung receive abundant blood and if they have not progressed beyond repair. Recovery can be promoted if therapeutic agencies minimize or eliminate the obstacles to spontaneous recovery.

Treatment consists primarily in improving the quality of blood in circulation and restoring its volume if it has been reduced but not because

of the lungs alone. Lesions, be it recalled, are never restricted to the lungs. Either an extrapulmonary focus was the source of the infection that has reached the lungs or bacilli from the pulmonary lesion have been disseminated chiefly through the systemic arterial blood and deposited on the nutritional surface of organs and tissues. The majority are destroyed. Some are inactivated. A few remain parasitic and produce lesions, possibly in the kidneys (Medlar). Other steps in treatment are to restrict further dissemination of bacilli and of noxious substances from the pulmonary foci, to increase the volume of blood delivered to the affected or more affected lung, thus to foster the efficacy of the defensive and reparative responses of its structural cells, to conserve myocardial competence and to develop and maintain a margin of safety which includes upholding morale.

Improvement in the Quality and Restoration of the Quantity of Blood in Circulation.—The need for well balanced diets, suitably prepared and served, is recognized but infrequently met. The sin of overfeeding is as common as is the neglect to utilize proper food to regulate the bowels. Constipation is a double menace, interfering with nutrition and favoring invasion or more often reinvasion of intestinal mucosa by bacilli swallowed with the sputum. Seldom do patients get enough water, fresh fruit and salads. Calcium, iodine and chlorine are insufficiently provided. Fresh air and sunshine, two necessities everywhere available, are seldom properly utilized. Outdoor living, night and day, requires sleeping porches and extra attention. This increases immediate costs but saves eventually. Perhaps one tenth of the patients are too ill to benefit from regulated exposures to sunshine. Certainly not one-tenth are allowed to profit from the beneficent influence that energizes the metabolism of all cells.[13]

13. Facts are available to contradict the harmful statements of those opposed to the therapeutic utilization of sunshine. Persons (excepting negroes) having moderate deficits in either cellular or noncellular blood elements who are otherwise living wholesomely will recover from their anemia if exposures to sunshine are properly regulated as suggested by Rollier, provided their hematopoietic structures are not exhausted. On the contrary, robust persons overexposed even once to real or artificial sunshine will develop deficits in both cellular and plasma constituents (e. g., lymphopenia and hastened sedimentation) that may persist for more than a fortnight. It is therefore evident that exposure of those suffering from moderate fatigue of hematopoietic structures must be initially brief and gradually increased, and those whose blood-forming units are exhausted will be injured by any exposure.

Both the beneficial and injurious effects are produced by emanations that penetrate the skin and are disseminated in blood and lymph. Sunburns and tan are reactions to overexposures and are to be avoided in therapy—burns because they are indicative of injury, tanning because it is protective against the penetration of the skin by emanations and necessitates longer exposures to provide desirable benefits and leads to additional pigmentation. Hence the wisdom of gradually

Artificial light which reproduces the entire spectrum of sunshine quite accurately can be furnished and is a satisfactory substitute, but only a substitute. Artificial lights that produce parts of the spectrum are less efficacious. Drugs avail little. Intravenous administration of dextrose and salt is valuable to overcome dehydration and alkalosis. When repeated examinations of the blood show that blood formation continues to be subnormal under this regimen or that blood deficits are serious at the beginning of treatment, transfusions, often multiple but of unmodified blood, are indicated unless patients are irreparably involved.

Restriction of Dissemination of Noxious Products and Bacilli.—Limitation of excursions of both lungs is attainable by mental and physical rest. A further restriction but not abolition of excursions of the affected or more affected lung is quite imperative. It can be provided by reducing the intrapleural negative pressures on that side either by artificial pneumothorax or preferably by induced paralysis of the diaphragm.

Fostering Defense and Reparative Responses of Tissue Cells.—Restriction but not abolition of usual activities and hyperemia are required. Means to restrict motion and the amount of blood needing aeration and filtration have just been described; those to increase the blood supply follow. Sometimes cavities must be allowed or compelled to collapse by the further reduction or abolition of intrapleural negative pressures. Induced pneumothorax may be utilized. Partial or complete thoracoplasty is usually demanded.

Increase of Amount of Blood Delivered to Lung.—Parenchymal nourishment and defense are supplied chiefly by the blood delivered through the bronchial arteries which are under vasomotor control. The unit volumes of blood delivered are greatest if the peripheral resistance is minimized and vasoconstriction prevented. Peripheral resistance is least when the lung is in a mean position between the extreme of inflation and deflation. Vasoconstriction is caused by chilling of the body and complete inactivation of the lung. Keeping the body warm and reducing intrapleural negative pressures fill these requirements. Increased metabolism of tissue cells adjacent to bacilli produces the excess catabolic products needed to induce local hyperemia.

Conservation of Myocardial Competence.—Restriction of toxemia, adequate nourishment, rest in bed during the active phases of the disease, and thereafter gradually progressing activation are required. Most

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exposing increasing areas of skin so that maximal effects are attainable in brief intervals. Likewise it is inexpedient to expose to sunshine during midday in the summer or to highly powerful artificial lights. The notions that the thoraces of patients suffering from pulmonary tuberculosis should not be exposed and that any exposures provoke hemorrhage are obviously erroneous.

important of all is the provision of an adequate volume of wholesome blood, and second to this, the limitation of the peripheral resistance within the vessels of the lung, which is attainable by the avoidance of positive intrapleural pressures.

Margin of Safety.—A supply of reserve energy during the disease is hardly more necessary than it is throughout life after convalescence. If the capacity of the entire circulatory unit to make and to deliver blood is developed and not dissipated, the utmost has been accomplished.

Morale.—The will to recover and to keep well is aggressive optimism. Optimism is developed and maintained with the realization that suitable efforts are being made to promote mental as well as physical welfare. Gaining in strength alone is of little value without a desire to work and an anticipation of the reward of accomplishment. Nothing is more productive of pacifistic pessimism than the expectant therapy that procrastinates until body and soul are wrecked.

SURGICAL ASPECTS

Operations suitably performed on properly selected patients are efficacious in promoting recoveries or in aiding to arrest the disease. Failures have taught the invaluable lessons of what not to do and when not to do anything. Successes indicate greater service, particularly to many who are being denied a more certain and less delayed return to active life. A summary of experiences gained while attempting to promote recoveries by a utilization of procedures based on concepts of the pathology of tuberculosis and of the physiology of external respiration will be given to indicate possible attainments.

TRANSFUSIONS

Unmodified blood has been given with paraffined tubes.[14] Many patients have received one, some three or four, and a few seven or more transfusions.

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14. Among the objects of transfusion are to increase the volume of blood in circulation, to raise its oxygen-carrying capacity, to add both lymphocytes and protective substances or antibodies, and to avoid causing febrile reactions.

Anticoagulants now available are injurious to lymphocytes and to antibodies. Margaret Perry (Wisconsin M. J. **25**:123, 1926) found lithium citrate to be the least harmful. All of the fibrinogen is not inactivated and is changed into substances that approach fibrin in structure. These substances are sufficiently irritating to cause chills, particularly in the febrile patient, whose thermo-regulating apparatus is unstable. Chills are distinctly more injurious than helpful and may be lethal. Syringes are not used for the same reason. They injure blood more than do paraffined tubes and thus initiate the conversion of fibrinogen into fibrin. Chills occur less frequently after syringes are used than after anticoagulants are employed but more frequently than when transfusions are given with Vincent tubes.

Indications.—Serious blood deficits, preparation for operation, postoperative hypotension, and incipient acute pneumonia especially in the less affected lung are indications for transfusion.

Contraindications.—Transfusion is contraindicated in the presence of irrecoverable incompetence in the blood-forming structures or in the heart muscle.

Failures.—Once the capacity to form cellular or noncellular constituents of the blood is lost or the myocardium is irreparably damaged, transfusions, no matter how often repeated, are futile though they may prolong life for a few weeks or even months.

Successes.—Restoration of the quality and quantity of blood has been achieved, and the rest thus provided has permitted the circulatory apparatus to recover its competence. Sometimes when the heart is weak, it has been necessary to give only 100 cc. at a time; usually 500 cc. has been given and as slowly as the avoidance of coagulation permitted. Patients have been prepared to withstand operations that would otherwise have been exceedingly hazardous. Similarly they have been relieved of ominous postoperative hypotension. Rarely a transfusion has been given during operation, though usually dextrose is given if blood pressures fall below safe limits. Transfusions given as soon as signs of an acute pneumonia are recognized can, because of the resultant overdistention of the pulmonary capillaries, overcome atelectasis, and promote immediate recovery from the infection.

The interdependence of lesions and blood status has been proved. Nothing added to the routine treatment of patients but the giving of blood has induced improvement that cannot be otherwise interpreted. Another proof was obtained accidentally. A large man who had recovered from a rather brisk form of the disease had been used as a donor for a very sick patient, and his blood was more beneficial than that of the usual donors. Shortly afterward a nurse became acutely ill and needed blood immediately. He volunteered to give his blood, and this additional reduction was followed by a recrudescence which, fortunately, was brief. When doubt arises, it is safer to transfuse than to wait for positive indications. One transfusion too many never hurt a patient; many fail to obtain full benefits if there is one too few.

The selection of donors is also of importance. Those recently recovered from the disease are seldom available and, as experience proves, should be used only under unusual conditions. Robust persons over 30 years of age and more particularly men who have had tuberculosis and acquired insusceptibility are most suitable. They have potent antibodies in their plasma, the substances which restrict the metabolism of bacilli, help to neutralize the noxious products and contribute the most effective single element to antagonism.

INDUCED PARALYSIS OF THE DIAPHRAGM

Paralysis and subsequent rise of the diaphragm reduces intrapleural negative pressures (in man and other thick-pleuraled animals but not in the thin-pleuraled) and causes deflation of the lung on the side affected. Vital capacity is reduced upward of 10 per cent. In some patients the intercostal spaces are narrowed, and the angle between ribs and spine becomes more acute immediately or some weeks after paralysis. This handicap is not great, but suffices to justify induction of permanent paralysis only when recovery of function of the diaphragm would be impossible after the pulmonary lesions have healed.

Three procedures are employed: crushing (phrenemphraxis) of the main branch of the phrenic nerve or, in addition, of such accessory branches as contain filaments that transmit motor impulses to induce temporary paralysis and, if possible, complete relaxation; excision (phrenisectomy) of portions of the trunk or accessory branches of the phrenic nerve to induce permanent complete paralysis and relaxation; extraction of the distal portion of the phrenic nerve (exeresis) when phrenisectomy fails to induce complete paralysis and relaxation.

All operations are performed with patients lying on a fluoroscopic table. The position and contractions of the diaphragm are observed. Then the phrenic nerve is exposed through a supraclavicular transverse incision, the main trunk held gently in a narrow hemostatic forceps, the lights extinguished and the x-rays generated. Sudden crushing causes the diaphragm to contract and then to rise abnormally high. If all the motor fibers have been blocked, the diaphragm does not descend during inspiration, and its contour remains evenly rounded. If some filaments transmitting motor impulses lie in accessory or collateral branches (less than 40 per cent), then on inspiration wavy indentations appear in the contour produced by the unparalyzed segments. Collateral branches are sought and the process repeated until the paralysis is complete; i. e., there is no intrinsic motion though the paralyzed side may be drawn downward by contractions of the opposite side. Branches of sympathetic nerves transmit impulses that help to preserve the tone of the diaphragmatic muscles. They may join the phrenic in its cervical or thoracic portions or reach the diaphragm separately. Until these nerves are blocked, the diaphragm retains some of its tone and is incompletely relaxed. When they are all blocked, relaxation is complete and the atonic diaphragm rises during inspiration, producing the characteristic paradox.

If phrenemphraxis as just described produces desired results and it is expedient to make them permanent, the nerves containing motor fibers are divided at the place where they have been crushed, a few inches of the distal portion withdrawn and divided as low as exposure permits.

When the phrenemphraxis is inefficacious, exeresis is utilized. The main trunk is divided and the distal portion extracted slowly until the nerves are disrupted. Even this procedure may fail occasionally to induce relaxation or even complete paralysis.

Indications.—Temporary paralysis is used for incipient lesions and for moderately advanced lesions which are of such nature as to indicate probable healing in four months or less and a return of motion will be helpful in restoring vital capacity, for recurrent hemorrhages from the pulmonary artery and for pain. Permanent paralysis is induced as a preliminary step to thoracoplasty if return of motion is undesirable.

Contraindications.—Immobilization, high position and fixation of the diaphragm by dense adhesions over the lower lobe, immoderate susceptibility revealed in irremediable blood deficits, and approaching death are contraindications for produced paralysis.

Failures.—Occasionally it is impossible to find accessory branches that transmit some of the motor impulses to the diaphragm, and crushing induces only partial paralysis. Not only is motion incompletely inhibited but also the diaphragm retains enough tone to prevent its displacement upward. Rarely exeresis will not induce complete paralysis, some innervation of the diaphragm being supplied by the lowest intercostals.

Paralysis of the diaphragm, however complete, will accomplish little for those of immoderate susceptibility even if their lesions are not advanced. It is only a part of treatment, and, unless accompanied by all other measures, it will often fail to promote improvement. Those who expect induced paralysis to be a panacea are disappointed because they do not rely on careful physical and fluoroscopic examinations, do not consider personal and family history, and neglect to estimate hematopoietic capacity.

Successes.—The greatest help obtainable from transient paralysis is for incipient lesions. Recovery, if patients are of lesser grades of susceptibility, is hastened. Improvement in similar types of patients whose lesions are more advanced is usually pronounced and progressive and may even lead to their dismissal from an institution within four months as apparently recovered. Sometimes a recrudescence then proves that the disease had been arrested with the aid of paralysis and was reactivated by a return of motion. Patients with advanced lesions may be made more comfortable through restriction of pain and cough. Some are helped mentally for a time. A notable service is in preparation for thoracoplasty. Hemorrhages from the pulmonary artery are usually controlled. Pain can sometimes be checked. Occasionally the sensory nerves are in accessory branches so that blocking only the main trunk of the phrenic nerve is useless.

Reduction in intrapleural negative pressures and consequently in the inflation and excursion of the lung increases its blood supply, raises pleuropulmonary resistance to invading bacteria, augments defense and repair, and does not increase cardiac labor. It is a natural adaptation to combat acute pleuropulmonary irritation and is accomplished by spontaneous reflex atonicity of the diaphragm, increased angulation of the ribs and restricted motion of the thoracic cage on the affected side. Induced paralysis of the diaphragm affects the same reflex arcs and is similarly effective. It is not the treatment of tuberculosis but is a dependable adjunct to other methods. The earlier it is employed, the more benefits it will confer if the trifling operation is performed carefully and permanent paralysis is not induced when transient paralysis would suffice.

Pneumothorax, properly induced and repeated, will provide an inconstant reduction in intrapleural negative pressures. It creates a lesion, a cavity filled with an irritating gas. Instead of effecting a natural and dangerless adaptation, it imposes an abnormal state, not without danger, that is less beneficial.

THORACOPLASTY

Extrapleural resection of ribs is not a definite procedure such as an amputation or removal of a gallbladder but a means to alter intrathoracic tension. Alterations attained depend on the number and location of ribs resected, the extent of the resection, the presence or absence of pleural adhesions and the elasticity of the lung.

The utmost accomplishment of complete thoracoplasty is to subject an entire lung to atmospheric pressure and produce its collapse. This permits the lung to adapt itself naturally and to retain a suitable supply of bronchial arterial blood during and after the interval of readjustment without imposing intolerable burdens on the heart if operations are performed in three or more stages. Fortunately, the lung is not compressed, its blood supply is not harmfully curtailed and the heart is not overburdened. Addition of pressure to the parietes after ribs are removed is worse than futile.

Indications.—Existence of cavities that cannot collapse because their walls are too rigid or because they are fixed by pleural adhesions to parietes demands thoracoplasty to provide opportunities for arrest of the disease or recovery from it. Limited thoracoplasty is indicated if the cavitation is restricted to an upper or a lower lobe and the balance of the lung is so little affected that it can recover and contribute to external respiration and other pulmonary functions. Complete thoracoplasty is indicated if cavities exist in more than one lobe or if they are confined to one lobe and the lesions in the balance of the lung suffice to have

destroyed its capacity to regain function; if incomplete, thoracoplasty fails to promote arrest or recovery.

Contraindications.—Loss of blood-forming powers, pronounced and irreparable myocardial incompetence, progressive bilateral lesions and lack of morale are included in the contraindications.

Methods.—Patients are selected who have an opportunity to recover. Rib-cutting will not rehabilitate the dying and is never justified merely because everything else has been tried and has failed. Preparation extends over a week or longer. It consists of a preliminary paralysis of the diaphragm, restricted activities, excess of water and fruit juices in the diet, intravenous administration of salt and dextrose, and, when feasible, one or more transfusions.

Local anesthesia is employed if the mental or physical distresses will not be too objectionable. Ethylene given under slightly increased pressure is the safest general anesthetic. The pressure prevents postoperative atelectasis. One stage may be done with local, the next with ethylene or as the patients elect, or operations may be begun under local and be completed under general anesthesia.

Resections begin with the uppermost or lowermost ribs according as they overlie the most serious lesions, and are repeated when the patient's condition warrants. The number of ribs resected at any stage should be one less than the patient can withstand. If the first operation or two introduces progressive improvement, others are postponed to make certain they are necessary. Undue delay is to be avoided as ribs regenerate and may require a second resection which is more difficult. Resection of the lower six or seven ribs may include all the periosteum and the intercostal muscles. Wound healing is excellent, and, after the edema disappears, the parietes which consist of the parietal pleura, skin and subcutaneous fat are soft and yielding. This permits of a wide range of adaptability and prevents interference with cardiac action by adhesions. Some patients are annoyed by being able to put a hand almost directly on their heart. It is not yet certain whether or not this prophylactic decompression of the heart is wise although it is harmless.

All ribs except the first and twelfth are removed from their angles to the sternum in complete thoracoplasty. If the paralyzed diaphragm is high, the eleventh rib is spared to assure saving the nerve supply to the upper portion of the rectus muscle. When conditions permit, the mesial portions of the five upper ribs are not resected to restrict deformity. Postoperative care includes transfusions, dextrose and salt intravenously, opiates and fresh air.

Failures.—Deaths are restricted to mistakes in selection of patients, to accidental wound infection and to acute pneumonia. Myocardial

incompetence limits subsequent activity. Lost morale may prevent repetition of resections needed to permit of healing or arrest of lesions.

Successes.—Proper selection and preparation of patients, restricting the number of ribs resected at any stage within limits of toleration and suitable after-care make thoracoplasty feasible for seriously handicapped patients. Performance of operations earlier, that is, as soon as it is probable that healing cannot occur until intrathoracic tension is appropriately altered, reduces both the number of ribs that must be resected and the period of convalescence. A larger proportion of patients can return to gainful occupations and, because their vital capacity is less curtailed, they are able to take positions that demand considerable activity. Many can resume their former vocations.

Proceeding in accordance with the plans outlined has made it possible to avoid fatalities from thoracoplasty, and no patient with a chance for recovery has been denied operation. This has been accomplished through cooperation with the medical men who have had direct charge of patients. Moreover, earlier and more general utilization of transfusions and induced paralysis of the diaphragm has reduced the number of patients who have needed rib resections and also the number of ribs it has been necessary to remove.

The problems incidental to tuberculous abscesses of the lung, cavities as they are usually designated, need solution which thoracoplasty does not provide. For example, an upper lobe may be converted almost completely into cavities and the balance of the lung remain quite unaffected, or, following a complete thoracoplasty, an abscess of considerable size may persist and continue to make mischief. Destruction of an involved lobe by the actual cautery as employed by Graham might be efficacious if sinuses did not persist. Were this procedure successful, it would be preferable to partial thoracoplasty. External drainage of abscesses already practiced by Lilienthal is perhaps more widely applicable than now seems probable.

SUMMARY

Prevention.—Pulmonary tuberculosis occurs because human, bovine and avian tubercle bacilli are deposited on the external and aerating surfaces of lungs and penetrate them to invade the parenchyma of such persons as are susceptible because they are unable to make suitable cellular and noncellular constituents of the blood.

Reduction in the number of bacilli now present in the air and ingesta is the primary requisite. The second is to improve living conditions. The third is to prevent reproduction of those whose hematopoietic structures are inherently weak.

Treatment.—The causes of the inception, the influences that govern the evolution of phthisis, and the factors that contribute to systemic and

pulmonary antagonism are fairly accurately established. Enough has been learned of how the factors can be modified so as to aid patients to recover or to arrest their disease to eliminate empiricism and routinism from phthisis therapy.

The procedures now available, nonoperative and operative, suitably and promptly utilized would diminish disabilities and reduce the present mortality rate more than has been hitherto possible. In addition to improving present procedures and a wiser utilization of them, the great obvious need is a potent antiserum.

GENERAL SUMMARY

Virulent tubercle bacilli are deposited so frequently on the external surfaces of the body from air, contacts and ingesta that every one is a carrier although most of the microbes do not survive. The surfaces are penetrated repeatedly with and sometimes without the provocation of superficial lesions. The bacilli enter the subcutaneous tissue and the gastro-intestinal and bronchial submucosa wherein some are deposited on the outer surfaces of blood capillaries and lymphatics.

Bacilli have now become invaders, and, being obnoxious, they arouse the antagonism of the host, namely, the increased activities of the adjacent tissue cells which are supported, reenforced and stimulated by the addition of cellular and noncellular constituents of the blood. A majority of the invaders are destroyed. The survivors are inactivated if the antagonism presented by the host is effective enough to confer insusceptibility, otherwise they maintain or regain their destructive activities according as the host, because of the degrees of inefficacy of antagonism, is more or less susceptible. A minority of surviving invaders remain in the subcutaneous and submucosal tissues and provoke or do not provoke lesions according as they maintain or regain activity or are reactivated. The others penetrate lymphatic and blood capillary walls or are carried into the lymphatics within wandering phagocytes.

Bacilli that enter blood capillaries after having penetrated the skin or the bronchial mucosa are transported in the venous blood and delivered through the pulmonary artery to the lung where most of them are deposited on the aerating surface, the endothelium of the capillaries of the lesser circuit. Bacilli that enter blood capillaries after having penetrated gastro-intestinal mucosa are transported in venous blood to the liver where most of them are deposited on the endothelium of the capillaries of the portal circuit within the liver.

Bacilli that enter lymphatics after having penetrated the skin are transported to adjacent regional glands and deposited on the endothelium of the intraglandular sinuses of the first or second gland. Bacilli that enter lymphatics after having penetrated the bronchial mucosa are transported to peribronchial glands or to hilum glands and deposited on the

endothelium of the intraglandular sinuses. Bacilli that enter lymphatics after having penetrated intestinal mucosa are transported with the chyle during active digestion through lymph glands, but not all are deposited on the walls of sinuses. The others are carried into the receptaculum chyli and promptly delivered through the thoracic duct into venous blood and thence to the lungs.

The bacilli that enter the venous blood of the systemic circuit, those that enter the blood of the portal circuit and are not deposited within the liver, and those that enter the blood with lymph in the thoracic duct are all delivered to the lung through the pulmonary artery.

Most of the bacilli in venous blood are deposited on the walls of the pulmonary capillaries, and the few that escape are disseminated throughout the body in arterial blood and deposited on the endothelium of the capillaries of the systemic circulation within every organ and tissue. Available evidence indicates that the larger proportion of invaders have penetrated the intestinal mucosa and are the more usual cause of pulmonary infection because they are frequently delivered promptly, directly or indirectly, into the venous blood.

This completes the first phase of invasion, namely, penetration of an external body surface, destruction and retention of some bacilli in submucous or subcutaneous tissues, dissemination of the balance through blood and lymph, and their deposition on the endothelium forming the aerating surface of the lungs, the digestive surface of the liver, the nutritional surface of every structure in the body, and the drainage surface (lymphatics) of all structures but the central nervous system, eye, internal ear and spleen which have none. Superficial and subsurface lesions are provoked if the surviving bacilli continue active in spite of antagonism; none, if they are inactivated by the antagonism of the host.

Subsequent phases of invasion are quite identical. Bacilli have been deposited on one of the surfaces (nutritional, drainage, etc.) of organs or tissues. The majority do not survive. Some of the survivors penetrate their internal surfaces and enter the parenchyma of organs and the cells of tissues instead of subcutaneous and submucous tissues. Again the majority are destroyed. Some of the survivors are retained in situ and may or may not provoke lesions. The balance are disseminated.

Organs particularly active in the physical and chemical filtration of blood and lymph (lung, liver, kidney, spleen and lymph glands) are the more often invaded and more liable to develop lesions.

Organs inactive in filtration (thyroid, muscle, brain, epiphysis of bones and fascia), whether they receive more or less blood, are less often involved and the less liable to develop lesions.

Every individual is invaded repeatedly, and presumably every organ and every tissue is invaded at one time or another.

Invading bacilli provoke lesions only if the antagonism of the host, provided by the responses of the cells of the structures invaded and the cellular and noncellular constituents of the blood, is insufficient to destroy or to inactivate the bacteria.

Responses of tissue cells contribute less to antagonism than to the cellular and noncellular constituents of the blood, and the noncellular constituents contribute more than the blood cells.

All contributions are essential to the development of the effective antagonism that provides insusceptibility.

Deficits in these contributions impose corresponding degrees of susceptibility.

Deficits in the noncellular constituents of the blood (namely, in the production of an abundance of sufficiently potent antibodies) are a constant factor imposing susceptibility; deficits in the number and stamina of blood corpuscles are a common factor.

Deficits in the effectiveness of responses of cells of tissues and of those forming the parenchyma of organs determine the location of lesions which are not limited to one organ or to a single tissue.

All forms of tuberculosis are systemic infections in which the predominant lesions occur in divers structures, e. g., lungs, genito-urinary and digestive tracts, lymph glands, bones, central nervous system, serous membranes, meninges, fascia, etc.

Pulmonary tuberculosis is the most common form of the disease because of the frequency of invasion by bacilli that have penetrated the external surfaces of the body and are disseminated through the blood, delivered to the lung through the pulmonary artery and deposited on its aerating surface.

Pulmonary tuberculosis is likewise the commonest serious concomitant or sequel of other forms of the disease.

Inception of pulmonary tuberculosis is attributable: first, to deficits in the constituents of the blood; second, to the frequency of invasion of the lung; and finally, to the inefficacy of the tissue responses, which are normally adequate but are often impaired by the scars of previous injuries and existing inflammations.

Treatment of all forms of tuberculosis includes improving the quality and restoring the volume of blood in circulation, increasing the volume of blood delivered, particularly to structures harboring the predominant lesions, restricting the activities of these structures to reduce dissemination of noxious products that cause the toxemia and of tubercle bacilli.

These measures are identical with the natural responses to focal and disseminated irritants which, when effective, produce spontaneous recovery and not infrequently confer insusceptibility. They should begin with recognition of the disease, even though it is incipient, and be con-

tinued after convalescence to obviate recrudescence or reinfection. Thus only will convalescence be hastened, disabilities be minimized and active life prolonged.

Treatment of pulmonary tuberculosis differs from that of other forms because of the peculiarities of the structure and functions of the lung and of its sensitiveness to alterations in tension.

Treatment of pulmonary tuberculosis cannot be fully effective unless operations (induced paralysis of the diaphragm, transfusions of unmodified blood and thoracoplasty) are added to other measures (rest, diet, fresh air, sunshine, etc.).

Application of pathology by the administrators of institutions, a further understanding of the potentialities and limitations of operation by internists and surgeons, and constant cooperation are requisite to progressive accomplishments.

CONCLUSIONS

Pathology and experience have defined therapeutic principles and indicated their application.

The incidence of all forms of tuberculosis will be materially reduced with reduction of the number of tubercle bacilli in the air and ingesta. Until this is accomplished wholesome methods of living, greater care in the selection, preparation and service of food, and the avoidance or correction of stasis and lesions in the gastro-intestinal tract are the most necessary preventive measures.

No form of tuberculosis can be cured in the sense that all bacilli can be removed from the body and reinvasion prevented.

Recoveries can be promoted for all forms of tuberculosis by augmenting the natural responses which lead so often to spontaneous recoveries.

In the treatment of pulmonary tuberculosis nonoperative measures alone and operative procedures alone cannot augment natural responses to their highest level of efficacy.

Prompt utilization of appropriate combinations of nonoperative and operative therapy is requisite to afford each patient the opportunity to achieve undelayed recovery.

Internists and surgeons who attempt to treat patients suffering from pulmonary tuberculosis are obligated to understand the potentialities and limitations of operative and nonoperative measures so that they may have the same working knowledge and differ only in the procedures they employ.

A common appreciation of the problems presented by each patient should promote study and investigation, prevent not only procrastination but also the subjection of patients to needlessly hazardous or crippling operations and to futile operations.

DIRECT DRAINAGE OF TUBERCULOUS PULMONARY CAVITIES

HOWARD LILIENTHAL, M.D.
NEW YORK

Until comparatively recent years I had an idea that it would be dangerous, or at least unwise, to open deliberately a tuberculous cavity of the lung, as has been customary in nontuberculous abscesses.

While my experience is extremely limited, I am convinced that the danger of this procedure is not as serious as I had thought, and that great improvement may follow an operation of this kind. I had believed that openings into these cavities would never heal, and that the danger of hemorrhage was always present. Thus far, however, in three cases in my own practice, I have seen no hemorrhage, and the tendency toward the formation of a permanent fistula seems to have existed in proportion to the degree of collapse of the walls of the cavity. I do not here include direct bronchocutaneous stomas.

The cases in which this mode of surgical therapy should be selected are of two varieties: (1) those in which there is a virulent mixed infection with the clinical signs of pulmonary abscess, and (2) those in which a cavity cannot be collapsed without great danger to life and in which the accompanying sputum is so abundant that it threatens to spill into the opposite lung and to produce an extension of the disease.

Regarding the latter class, one must be fairly certain that the expectoration is coming from the cavity. This is not always so, for some cavities have a nonsecreting fibrous lining, and the discharge which appears as expectoration has its origin in other parts of the lung, often from bronchiectatic lesions.

There are two methods of draining these cavities: first, from the lung directly and, second, from the tuberculous cavity into an accompanying empyema, the condition thus being converted into one of pleuropulmonary fistula.

REPORT OF CASES

CASE 1.—Fanny S. was first seen by me five years ago, when she was 37 years old. At that time she had been ill for fifteen years with pulmonary tuberculosis. Soon after her first visit, a roentgen examination revealed extensive disease of the left lung with several cavities containing fluid (fig. 1), one of them as large as a small lemon near the hilum of the right lung posteriorly. There was some fibrosis with displacement of the mediastinum toward the more diseased side. The left lung was the seat of numerous healed lesions which had become calcified. There were no cavities here. Incidentally, she had enteritis, a perforated nasal septum following operation and a tuberculous disintegration of the right wrist.

The Wassermann test, suggested by Dr. James Alexander Miller on account of the perforated septum, proved negative. Dr. Miller agreed that the case was suitable for thoracoplasty.

On May 23, 1929, I resected the first five ribs, and three days later 400 cc. of whole blood was given (Dr. Nathan Rosenthal). Ten days after the first stage, I completed the thoracoplasty, resecting the remaining ribs including the tenth. Following this operation expectoration was greatly increased, the hemoglobin dropped from 85 to 60 and there was a distinctly septic picture. Roentgen examination now indicated that the cavities had been little or not at all influenced by an otherwise satisfactory collapse, so that two weeks later I operated again.

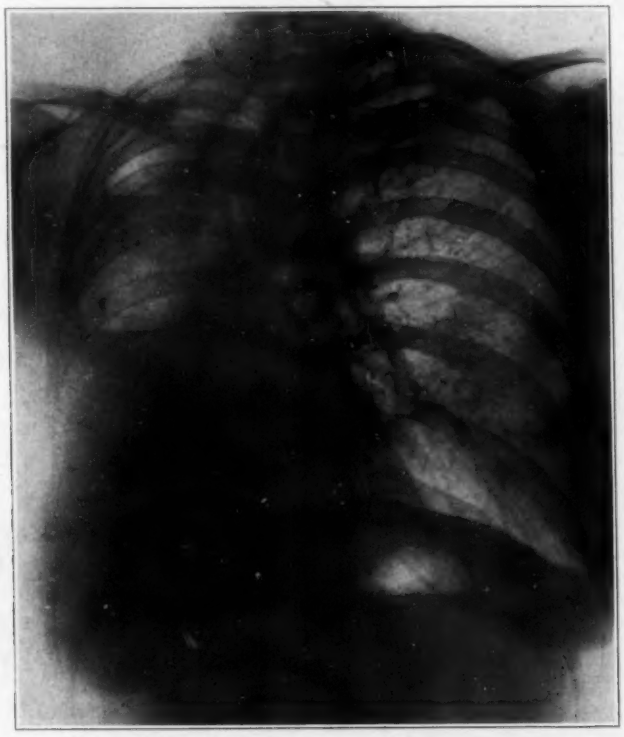

Fig. 1 (case 1).—Roentgenogram made before operation, showing two pulmonary cavities with fluid levels. Note the extreme retraction of the mediastinum including the trachea; the opposite lung is inactive.

At this time the patient seemed almost moribund. The wound was foul. Apparently there had been mechanical interference with drainage into the bronchial system. It was not necessary to cut ribs; I was able to attack the abscess directly through the wound, first passing a needle through extremely tough tissue, following the needle with a grooved director, and then divulsing with dissecting scissors.

The cavity proved to be bilocular (see two levels in fig. 1) with liquid pus in the lower chamber and mucopurulent material in the upper one. Fetor was present. The septum between the two chambers was divided throwing them into one, and the entire cavity was packed with rubber dam. Four hundred cubic centimeters of blood was transfused by the citrate method. A chill with a tem-

perature of 106.4 F. followed, but proved evanescent. The following day the rubber dam was removed and replaced by a number of small soft tubes. As soon as convalescence was established the patient entered Loomis Sanatorium, but was obliged to return to New York in a few months because the wrist had broken down and was discharging tuberculous pus. I performed a typical excision of the joint with excellent and apparently permanent functional and cosmetic results, but the principal interest centered in the behavior of the pulmonary cavity.

At first it acted like a nontuberculous abscess of the lung with profuse anaerobic discharge. Then gradually the odor disappeared, and mucopus, looking much like tuberculous sputum, took its place. The cough rapidly diminished, and for a time completely disappeared. There was a gain of many pounds in weight, so that the patient instead of being rather emaciated became actually obese. The

Fig. 2 (case 1).—Roentgenogram made after several operations (see text). The pictures were made with Bucky's diaphragm. (The scattering of spots is due to faulty photographic technic.)

temperature was never high, but only occasionally reached normal. The cavity diminished in size, but refused to collapse completely. I began to think that I had reached a final result, when much to my surprise the fistula insisted on closing. Unfortunately, however, with this closure there was a recurrence of cough, although with little expectoration. About a year passed during which the patient felt well, but she was prevented from going about among her friends because of constant irritating cough with only a slight amount of sputum. This became so annoying that I resolved to make one more attempt to obliterate the tuberculous abscess. On March 19, 1928, with the patient under general anesthesia, I resected ribs to the outer side of the abscess and pressed the walls of the cavity together by packing a rubber dam between the wall of the chest and the cavity. An opening of fair size was left at the site of the old fistula, and I hoped that com-

plete obliteration would follow. The immediate result was excellent, and throughout the summer the patient felt well and coughed hardly at all, and I thought a final success had been achieved. Then she caught cold, and the accompanying cough seemed to force the cavity toward the right side of the chest and seemed also to enlarge it by the pneumatic stress of the strain of coughing. The wound, which had been entirely cicatrized, reopened, and something more will have to be done to recollapse the walls of the cavity. In the meantime there is a slight elevation of temperature, usually less than 100 F. maximum, but the cough has recurred. This case is recorded, not as an example of cure, but to show a good temporary result in a case which seemed hopeless. From past experience with this patient, I believe that the problem of final closure is mainly mechanical.[1]

CASE 2.—G. R. M., a man, aged 37, was referred to me by Dr. Joseph L. Spruill of Jamestown, N. C. When he was first seen by me, there was an enor-

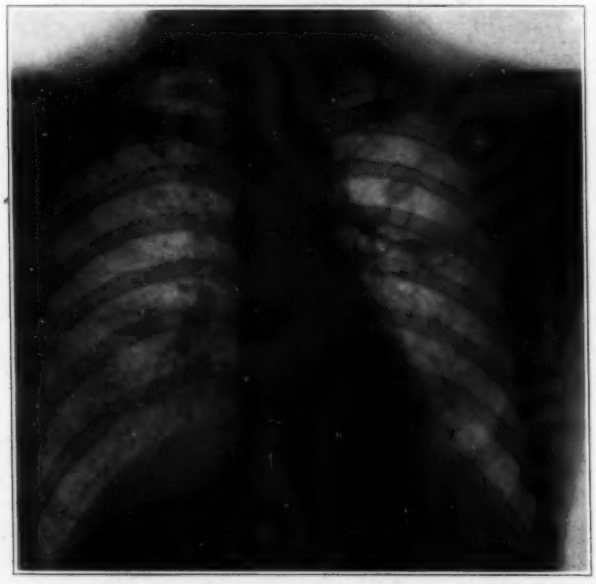

Fig. 3 (case 2).—Roentgenogram made before operation, showing enormous left apical cavity.

mous cavity of the left upper lobe, with tuberculous involvement of the lower left side of the chest as well, and an almost normal right lung (fig. 3). After several operations, including a complete thoracoplasty, a phrenic neurectomy and an apicolysis, the patient continued to cough and to show constitutional signs of the disease. I finally succeeded in collapsing the chest, but could not bring the walls of the large intrapulmonary cavity together. The best I could do is indicated in figure 4. Occasionally, roentgenograms showed a collection of fluid in this cavity, but as a rule it was apparently empty. In October, 1928, Dr. Amberson saw the patient with me; he said that he believed that the cavity was emptying into the lower part of the left lung and in this roundabout way was giving rise to the profuse expectoration. There was considerable cardiac deviation,

1. I expect to attempt closure by muscle flap implantation after a recent method devised by Pool and Garlock, soon to be published.

which perhaps accounted for much of the discomfort from which the patient suffered. Dr. Amberson strongly advised drainage of the cavity. The following day this was done, the patient receiving general anesthesia. It was necessary to incise the edge of the pectoral muscle near the middle of the scar following his apicolysis; the tissues were extremely tough, so that it was difficult to expose the walls of the cavity itself. This was eventually done, however, and a free opening was made, a number of necrotic plugs being wiped away with a sponge. When the cavity was opened, there was a sound of air rushing in or out, but after that no sounds indicating a connection with a large bronchus were heard, nor was there any bleeding at the patient's mouth. The finger exploring the

Fig. 4 (case 2).—Roentgenogram made after several procedures, including avulsion of the phrenic nerve. The cavity has been finally incised for drainage.

mesial wall of the cavity was so close to the aortic arch that no intervening tissues could be clearly appreciated. A large opening was made from the top to the bottom of this cavity. A roentgenogram made with the cavity packed with iodized oil gauze demonstrated that the gauze was actually within the lung. The discharge was fairly free, but was not copious. There was gradual improvement, and the patient went to his home. Later cough and expectoration almost or quite disappeared. Then he "caught cold," and the discharge both by mouth and through the wound increased.

One of the important and interesting points in this case is that in spite of my having widely opened this large tuberculous cavity, it was

impossible to maintain a free opening, and now the fistula is represented by a tiny, only slightly discharging aperture. The patient is at present at Loomis Sanatorium, where he continues to improve. The right lung has not changed since I first saw him and is in good condition.

The next case is of great interest because I believe that the procedure employed is one which should be followed in many cases of tuberculous empyema without pleuropulmonary fistula, and in which thoracotomy does not check the cough with its copious expectoration.

As I have suggested, it is generally conceded that profuse discharge through the upper air passages tends to implant the disease in the other lung. I am well aware that many cases can be cited in which prolonged expectoration of this kind has not been followed by contralateral extension, but these are not the ones which should guide one in treatment. It is the unfortunate spreading of the disease which therapy should prevent.

It seems to me that in deciding on operative treatment, one should consider the possibilities of a fatal issue if nothing is done rather than the mere cure of a condition which does not directly threaten life.

As an example, take chronic abscess of the lung. A surgical procedure looks dangerous because the disease may not be at once menacing, but when there are massive hemoptyses or a sudden extension of pulmonary gangrene it may be too late for surgical assistance. It is to prevent such possibilities that operation is advised rather than merely to check the annoyance of cough and expectoration. This principle is a general one and is by no means confined to thoracic surgery.

A method for dealing with open pyopneumothorax with profuse expectoration from the diseased side was suggested in this case by Dr. J. Burns Amberson, Jr., and I cannot do better than present a brief résumé.

Case 3.—M. C., a man in the forties, who had been ill for many years with bilateral pulmonary tuberculosis, presented dense infiltration with cavitation in the entire right upper lobe with less marked infiltration below. There was infiltration just outside the hilum of the left lung as well. The right side of the chest was treated by artificial pneumothorax, and while this was efficient below, the adhesions about the upper lobe were so dense that the capacity of the cavities was not influenced by the pneumatic pressure. The left lung meanwhile became "dependably quiescent." Fluid developed in the right side of the chest, and could not be eliminated in spite of aspiration and the injection of disinfectants.

Paravertebral thoracoplasty was performed with only partial success, the pleura being extremely dense and tough, so that full collapse was impeded.

Anterior rib resections were also performed, but with little effect. Then I attempted to compress the upper lobe by apicoylsis, and during the operation entered the pleura, which contained a large quantity of sanguinolent fluid. This, naturally, became infected, and a low thoracotomy for drainage had to be performed.

After every procedure the patient had a severe reaction, so that in spite of the large number of operations I approached each one with trepidation. Finally, although drainage from the thoracic fistula was free, the patient expectorated

more than 6 ounces a day from the cavities in the upper lobe. There was gradual decline, and I greatly feared that the left lung would become seriously involved and that he would die. It was then that Dr. Amberson saw him and made the suggestion that I should freely enter and expose the pleural cavity and deliberately open the lung so that the patient would expectorate into his pleura instead of through his mouth.

This procedure was undertaken on Jan. 5, 1928. Nitrous oxide and oxygen were administered by Dr. Branower. The operation proved more difficult, technically, than I had expected. I incised through the old posterior scar and exposed the ribs, which had become united by bony bridges of such ivory hardness that I had to use the chisel and mallet for most of the thoracoplastic work. Six ribs were thus divided as close as possible to the spine as well as in front of the cicatrix, and this entire part of the cuirass, consisting of six ribs united by bone, was removed in one piece. The pleural cavity was thus entered and a rib spreader applied. The exposure was perfect. The lung below the apex was found compressed into the spinal gutter by a leather-like investing membrane.

The adhesions of the upper portion of the upper lobe had to be severed from the wall of the chest with a heavy knife before the lung could be freed further with the fingers. I succeeded in peeling it entirely away from the dome of the pleura, and then attempted to locate the cavity from which the sputum was supposed to have come. There was no appreciable cavity, however, and I feared that I might be in danger of entering the trachea at this level. I decorticated this part of the lung of its leathery pleura; there was immediate collapse of the pulmonary tissue, which seemed to become a carnified contracted mass, and which at once moved down into the spinal gutter. This lung did not move on expiration nor expand with intrapharyngeal air pressure. I freely incised it, and small quantities of pus escaped. I then closed the wound in the chest with chromicized catgut sutures, leaving the skin open, however, and also leaving a space for packing so as to hold the lung against the rigid mediastinum. For the packing I used rubber dam and gauze. I then closed the skin with silkwormgut sutures in mattress fashion.

Transfusion with 800 cc. of citrated blood was then performed.

Following this operation there was, as might have been expected, considerable reaction, but the cough was greatly diminished, and there was almost no expectoration.

In this case one sees an enormous wound, extending directly into thickened pleura, tuberculous for many years. Healing was necessarily slow, and it was not until nearly three months later that the patient was well enough to be transferred back to Loomis Sanatorium. Under a careful hygienic regimen, including forced feeding, there was continued improvement, so that in the following autumn he returned to his home in Cuba. He has progressed satisfactorily ever since. The little sputum which he continues to expectorate has been reported negative by two laboratories in Havana. This, of course, is not to be taken as a sign of cure; it merely signifies that the disease is less active than it was.

The patient is up and about, although there are two small drainage fistulas: one in the lower part of the chest, and the other, a small, slightly discharging sinus, in the axillary region.

I report this case because I am convinced that the method should be employed more frequently when there is a closed pulmonary cavity discharging infected sputum by mouth and when there is an open tuberculous empyema.

SUMMARY

1. Two cases are reported in which improvement followed direct drainage of a tuberculous pulmonary cavity through the wall of the chest.

2. One case is reported in which an apical cavity discharging copiously by mouth was drained into an open pleural tuberculous empyema.

CONCLUSIONS

1. Improvement has followed the surgical drainage of tuberculous pulmonary cavities whether directly through the wall of the chest or into an open empyema.

2. The dangers of contralateral infection by implantation are diminished by the drainage of copiously secreting pulmonary cavities.

3. There is a strong tendency toward spontaneous healing of surgical openings into tuberculous cavities in the lung.

PHRENICECTOMY IN THREE HUNDRED CASES OF PULMONARY TUBERCULOSIS

E. S. WELLES, M.D.
SARANAC LAKE, N. Y.

It is not my purpose to go into the history of the surgery of the phrenic nerve, nor to review the literature on phrenic exeresis in the treatment of pulmonary tuberculosis. I desire merely to report the results in a series of 300 such operations, done on all types of tuberculous patients, and to determine what conclusions can be drawn as to the value of the procedure.

The operation is simple, involving division or crushing of the phrenic nerve in the neck in order to produce permanent or temporary paralysis of the diaphragm on one side. It is done under local anesthesia through an incision about an inch long placed accurately in one of the transverse folds of skin about an inch above the clavicle and with its center over the anterior scalene muscle which lies beneath the outer border of the sternomastoid. This incision gives a much less conspicuous scar than the vertical one, and in my experience, affords a more satisfactory approach to the nerve than the low one practically on the clavicle. If a temporary result is desired, the nerve is simply crushed with hemostatic forceps for about a fourth of an inch as it crosses the scalene muscle. If the accessory branch can be found, this is also crushed. Paralysis is obtained promptly, but function returns in from five to six months. To secure a permanent result, the nerve is divided, the lower end seized with forceps and by steadily pulling and twisting, several inches of nerve are evulsed. Often the whole nerve comes out, but a permanent result is obtained if only sufficient length is removed to assure breaking of the accessory attachment. This method of exeresis has always impressed me as being much simpler than the operation of Goetze, which involves the isolation and section of the accessory nerve.

Following operation, the hemidiaphragm rises about 2 inches (5.08 cm.) above its normal position and either remains stationary or has a slight paradoxic motion during respiration.

As to indications for the operation, my ideas have changed considerably with experience. At first it seemed natural to suppose that the procedure was best suited to basal lesions of the lung, and in Saranac Lake the first phrenicectomies were done in cases of this type. Gradually, and more or less experimentally, the operation was done in cases of upper lobe or apical lesions, and my co-workers and I were rather surprised to find it giving good results more often than in the cases in

which the lesions were in the lower lobe of the lung. The operation is now employed in all types of lesions. Naturally, it is used chiefly in unilateral cases, without regard to the lobe involved.

O'Brien [1] of Detroit has given a list of indications which agrees essentially with ours: namely, cases in which the patients are not doing well under ordinary rest treatment, but which are not considered sufficiently advanced for the use of artificial pneumothorax; cases in which pneumothorax has been attempted and found impossible on account of pleural adhesions; cases in which cavitation has occurred but in which thoracoplasty is not yet indicated; cases in which thoracoplasty is to be done and phrenicectomy is to be used as a preparatory measure; and

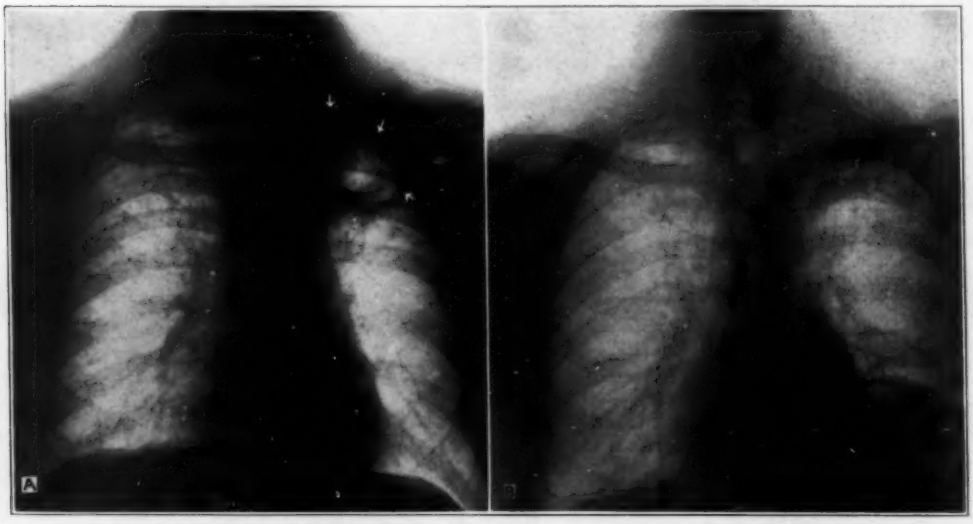

Fig. 1.—The roentgenogram on the left shows a large apical cavity before phrenicectomy; on the right, the same case after phrenicectomy with the cavity nearly closed.

finally, those cases in which the patients obviously need thoracoplasty but are poor risks, yet in whom we hope to get sufficient improvement following the operation on the nerve to prolong life, or ease symptoms, such as persistent tiring cough, with the possibility in mind that the more radical procedure may be attempted later.

The statistical results of the present series are as follows: Three hundred operations on the phrenic nerve are included in the study. As it was desired to determine the results of phrenicotomy only, twenty-three of the cases in which thoracoplasty had been performed subsequently

1. O'Brien, E. J.: Surgery of the Phrenic Nerve and Intrapleural Pneumolysis, J. A. M. A. **92**:463 (Feb. 9) 1929.

were left out of further consideration. Six of the patients have not been traced; so the total number on whom results have been checked is 271. Of these, 173, or 64 per cent, were improved by the operation, and 98, or 36 per cent, were not benefited.

The cases listed as improved vary from those in which the patient merely had some slight symptomatic improvement such as a decrease in cough or expectoration, or a lowering of temperature, to those who have been greatly benefited, with marked changes in the roentgen observations, diminution or actual obliteration of cavities, and complete disappearance of all symptoms. The list of failures includes a considerable number of hopeless cases in which the operation was done with faint

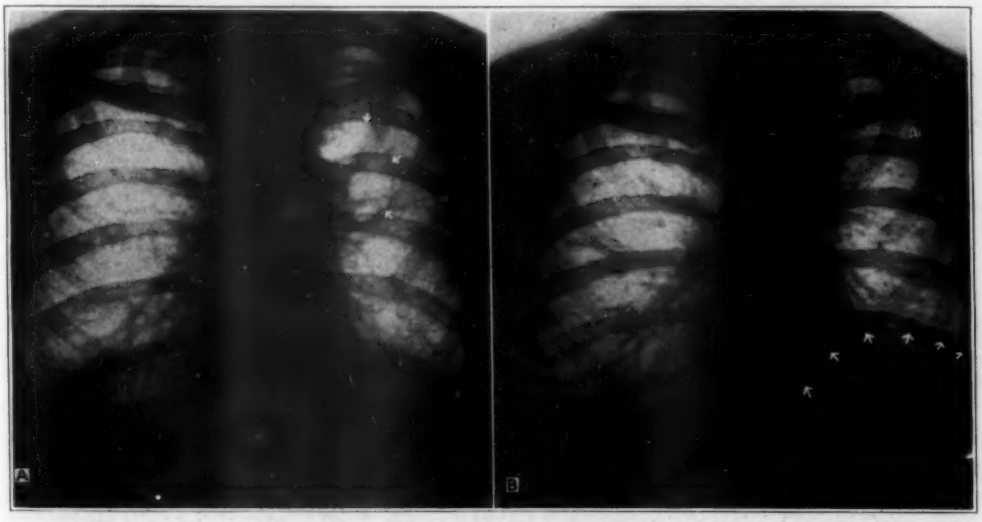

Fig. 2.—The roentgenogram on the left shows a multilocular cavity in the upper lobe of the left lung before phrenicectomy; on the right, the same case after phrenicectomy with the cavity closed.

hope of securing a good result. If these were deducted from the list of failures, the number of good results would be well over two thirds of the total.

In 1927, an analysis of our first hundred cases was made in the hope of finding a way to predict the result in any individual case from a previous examination of the clinical signs and the x-ray pictures. The present analysis of 300 operations is a continuation of the same study. We had hoped by this time to be able to give a fairly accurate prognosis and to be able to say with some assurance that the operation will help one patient and that it will not help another. In this hope we have been disappointed. In one case the operation will be promptly followed by

a contraction or complete disappearance of a good-sized apical cavity, with corresponding lowering of temperature, reduction of cough and expectoration and general improvement. We have had many cases like this; patients who have been steadily growing worse and whose cavities have been gradually enlarging in each succeeding x-ray picture up to the time of phrenicectomy, and who have thereafter gone on rapidly to a practical clinical cure. We operate on other patients with the same type of lesion, the same clinical progress and the same x-ray picture and get no improvement.

We do feel, however, that we can offer the operation to the patient with a reasonable assurance that it will do no harm, even if it fails to give any decided benefit. In 300 cases, we have had only five patients or less than 2 per cent, who have been made actually worse. Four of these five had basal cavities, and whether the rising diaphragm interfered with drainage or had some other effect, we do not know.

Few patients have any annoying dyspnea after the operation. In the few who do, it is usually of short duration. In a small number the rise of the diaphragm has been followed by digestive upsets, but the majority of these have been temporary. They have been no more common following left than right phrenicectomies. A small number have had a persistent tachycardia following operation—a rise in pulse rate from 10 to 20 beats per minute. This phenomenon I have been unable to explain, as the vagus nerve is never touched.

Only one accident has happened in the whole series of cases. In one of the early operations performed on the left side, the thoracic duct was cut completely across. For twenty-four hours there was a profuse flow of milky fluid from the wound, but a simple gauze packing stopped it, and there was no after-effect pointing to a loss of chyle from the blood stream. There has been no case of serious hemorrhage during the operation.

One interesting case involving bilateral phrenicectomy is included in the series. The patient was a man, aged 67, who came to Saranac Lake with a far advanced pulmonary tuberculosis of the left lung, chronic myocarditis and dyspnea. He had been hiccuping for long periods at a time for the preceding three months. A left phrenic exeresis was done in the hope of checking the hiccup. He had relief for twenty-four hours and then began again. One week later he called me in and asked me to cut the nerve on the other side. I explained the seriousness of the procedure and warned him that it might be fatal. He insisted, however, arguing that he was sure to die soon from exhaustion if the hiccups were allowed to continue. I consented and with considerable trepidation exposed the right phrenic nerve and crushed it. There was no increase in dyspnea and the hiccups ceased, only to begin again the

following day. I had made no attempt to crush or sever the accessory phrenic nerve on the right. The patient then ordered me to make a complete section. I operated once more six days after the crushing and did a radical exeresis on the right. Again there was no change in the breathing and the hiccups stopped permanently. The man lived for two weeks, and then his heart finally gave out. Both the persistence of the hiccup after exeresis on one side and crushing on the other, and the absence of increased dyspnea after complete paralysis of both diaphragms were interesting.

A number of experiments have been carried out in the use of phrenicectomy as an accessory to artificial pneumothorax. Several

Fig. 3.—The roentgenogram on the left shows bilateral apical cavities; on the right, the same case after left phrenicectomy with the left cavity completely gone and the right cavity greatly reduced in size.

years ago Alexander expressed the opinion, based at the time on theoretical reasoning, that diaphragmatic paralysis would be of distinct advantage in nearly every case of pneumothorax. He thought that it would lengthen the time between refills, decrease the chances of fluid, and by diminishing the thoracic volume, make it easier for the reexpanding lung to fill the chest completely when the pneumothorax was finally discontinued. In the main, our experiences in this line have been unsatisfactory, although it must be admitted that the number of cases of pneumothorax in this series is relatively small. I have seen one striking case illustrating Alexander's first point. A man who had a satisfactory collapse but who had to have gas promptly every nine days, was able

to go comfortably for three weeks or more between refills after phrenicotomy. In most of our other cases, however, there has been no beneficial result, even when there has been an adhesion from the lower lobe to the diaphragm which seemed to be interfering with satisfactory collapse. As a rule, the rise of the diaphragm in these cases is slight or absent. Whether there is any lessened tendency to fluid, I do not know.

Although I believe that the cessation of motion in the diaphragm is a more important factor than its actual rise into the chest in bringing about a good result, I do not believe that lack of motion before operation as observed by the fluoroscope is a contraindication to phrenicectomy. The clinical results are satisfactory in many cases of this type.

In six of twenty cases in which the nerve was crushed the patients were subsequently reoperated on and the nerve was extracted. These patients showed definite improvement for about five months and then began to relapse. In no case was there any difficulty about finding the nerve at the second operation.

I believe fully in the use of the operation as an accessory to thoracoplasty. It gives a better collapse and often does away with the necessity of removing the tenth rib.

CONCLUSIONS

Paralyzing the hemidiaphragm by evulsing or crushing the phrenic nerve is a simple procedure which is of distinct value in a wide variety of cases of pulmonary tuberculosis. Its value is fully as great in cases of apical lesions as in those in the lower lobe of the lung.

The operation gave beneficial results in approximately two thirds of a series of 271 cases.

Less than 2 per cent of the patients seemed actually made worse, so that it is reasonably safe to assure them that no harm will come of the operation even if it fails to do good.

THE ELECTROSURGICAL METHOD OF CLOSED INTRAPLEURAL PNEUMOLYSIS IN ARTIFICIAL PNEUMOTHORAX *

RALPH C. MATSON, M.D.
PORTLAND, ORE.

It is generally admitted that artificial pneumothorax is not only the most widely applicable method of collapsing the lung in the treatment of pulmonary tuberculosis but also the most valuable. Unfortunately, pleuritic adhesions are almost invariably present in cases in which the patients require pneumothorax treatment and constitute the greatest obstacle to a satisfactory end-result.

As a result of experience in the treatment of approximately 1,400 patients with pulmonary tuberculosis with artificial pneumothorax during the past eighteen years, my co-workers and I are convinced of the importance of establishing a type of pneumothorax which within a few months will give the diseased lung sufficient functional rest, collapse or compression to render it no longer a source of tuberculotoxemia or tubercle bacilli-laden sputum.

The importance of a satisfactory collapse of the lung is strikingly shown in the accompanying table. A careful review of the clinical records and stereoroentgenograms in 245 cases in this series reveals that the primary cause of failure of treatment with pneumothorax in 40 per cent of the cases was the presence of adhesions, which prevented a satisfactory collapse of the lung. In most of these cases, a temporary improvement followed pneumothorax treatment in spite of insufficient collapse of the lung. Consequently, the treatment was continued sometimes for prolonged periods, in the hope of stretching the offending adhesions and securing a good collapse of the lung. Sooner or later, however, either extension of disease took place to the opposite lung, intestines or throat, or some complication as empyema, spontaneous pneumothorax or obliterating pneumothorax occurred, compelling discontinuation of pneumothorax treatment. Unfortunately, the cases were then too far advanced to utilize other methods for collapse of the lung.

While adhesions are present in the majority of patients selected for pneumothorax treatment, according to our experience, a satisfactory pneumothorax can be established in 40 per cent of the cases.

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* From the Department of Thoracic Surgery, Portland Open Air Sanatorium, Milwaukie, Ore., and the Department of Medicine, University of Oregon Medical School.

In a similar percentage (40 per cent), however, the character of adhesions will prevent the necessary collapse or compression of the lung to provide adequate functional rest or closure of cavities; and in the remaining 20 per cent, pleuritic adhesions will prevent any introduction of gas. Thus, pneumothorax treatment will prove efficient in considerably less than half the cases wherein it is indicated.

The phthisiotherapeutist recognizes the value of thoracic surgery. In those cases wherein no gas can be introduced, he now more often takes advantage of the surgeon's ability to bring about collapse of the lung by a phrenic neurectomy or thoracoplasty instead of subjecting the patient to prolonged and unsatisfactory sanatorium care. However, the fate of cases presenting pleuritic adhesions, which prevent efficient collapse of the lung, leaves much to be desired.

The usual procedure in cases of this type is to keep up the pneumothorax frequently, month in and out, and sometimes even year in and

Comparative Value of Artificial Pneumothorax in Cases in Which Adhesions Did Not Prevent Adequate Functional Rest and Closure of Cavities, and Those in Which Adhesions Did Prevent Sufficient Collapse of the Lung to Close Cavities or Give the Necessary Functional Rest

Observations on 850 Cases. Jan. 1, 1911 to Aug. 1, 1925

Character of Pneumothorax	Clinically Well, Per Cent	Arrested, Per Cent	Dead, Per Cent
Satisfactory collapse, adhesions not preventing closure of cavites or adequate rest of the lung	48	20	21
Partial collapse, adhesions preventing satisfactory closure of cavities or adequate rest of the lung	13	13	50

out, especially if there has been some reduction in the quantity of the twenty-four hour sputum or its germ content, or if the patient has made some clinical improvement in spite of roentgenograms showing definitely that adhesions are preventing a satisfactory collapse of the lung. Admittedly, a small percentage of the patients in such cases recover, but the vast majority do not. The greatest indictment against the phthisiotherapeutist today, aside from not using collapse therapy as a whole to the extent it is indicated, is the continuation of a useless pneumothorax for prolonged periods, denying the patient the advantages of other recognized operative procedures.

Opinion will differ, of course, as to what constitutes a satisfactory pneumothorax. However, it is not to be decided only by the degree of collapse or compression shown in the roentgenogram, nor by the mere presence or apparent absence of adhesions per se. In one case, there may be only a thin layer of gas between the lung and the chest wall and the pneumothorax may be satisfactory, while in another case, there may be an enormous pneumothorax with displacement of the mediastinum, heart and diaphragm and with little lung tissue visible;

and yet, because of an uncollapsed cavity held open by adhesions, the patient may continue to expectorate sputum containing tubercle bacilli. It is a common observation of every phthisiotherapeutist that a single string or slender band adhesion extending from the partially collapsed lung to the thoracic wall frequently holds open a cavity and renders pneumothorax treatment a failure.

As a result of our experience, we have become convinced that pneumothorax will not give a satisfactory end-result if, after several months' trial, stereoscopic films reveal the presence of adhesions, the nature of which is preventing sufficient collapse of the lung or compression to bring about a satisfactory reduction in the amount and bacilli content of sputum from the diseased lung.

Careful roentgenologic study of adhesions in pneumothorax will show that they are more often distributed over the more diseased parts of the lung, being found almost invariably over superficial cavities. Consequently, the very part of the lung which is in greatest need of collapse is the least likely to receive it in an adequate measure.

Early in our experience with pneumothorax, we recognized the necessity of a satisfactory pneumothorax, but considered open operations or closed operations with the original Jacobaeus instruments too dangerous. We advocated instead that the adhesions be stretched by increasing the intrapleural pressure in order to secure a good collapse. Study of our end-results shows that this method was unsatisfactory, because not only did we seldom get a good collapse, but spontaneous pneumothorax was 40 per cent more common in cases in which we had resorted to the stretching of adhesions. The marked increase in spontaneous pneumothorax was undoubtedly due to tearing of the parenchyma of the lung or liberation of tuberculous foci from torn adhesions.

Four years ago, after Unverricht had developed his new thoracoscope, we again adopted the method of closed pneumolysis in all suitable cases. The general impression among phthisiotherapeutists and surgeons is that few cases are suitable for the operation. In studying the clinical records of stereoscopic films in ninety-one cases in a former series of patients now dead in whom adhesions prevented closure of cavities, we found that 40 per cent were suitable for pneumolysis early in their pneumothorax career; had they been operated on instead of being subjected to prolonged pneumothorax treatment, probably 50 per cent would be alive and well.

The value of the closed method of pneumolysis seems, by many, to be the least appreciated of any of the methods for collapse of the lung. This procedure is neglected for two reasons: The phthisiotherapeutist generally lacks the necessary surgical training and judgment, while the surgeon frequently lacks clinical experience in tuberculosis and

knowledge of pneumothorax as a background. Both are unwilling to spend the necessary time to perfect the technic. Thus, the surgeon favors the open method of pneumolysis, or thoracoplasty, while the phthisiotherapeutist clings to his partial pneumothorax. Both fail to appreciate the improvement in the technic of cutting adhesions, and many still retain the impression that it is dangerous.

These dangers are largely technical. Formerly, one worked pretty much in the dark with poor instruments and equipment. We, ourselves, went through this period and gave up the method, as we considered it dangerous and of little utility. Today, however, we have improved instruments and a more refined technic, and while the operation may be technically difficult, it is at least not dangerous when properly done.

If collapse therapy is indicated, it is our policy to try artificial pneumothorax. If a satisfactory collapse of the lung is not obtained within a few months, and it is shown on serial stereoscopic films that adhesions are preventing a satisfactory collapse, we consider a pneumolysis at once.

During the past four years, the patients in 45 per cent of our cases in which there was unsatisfactory collapse have proved suitable for the operation. If not suitable, we consider other methods of collapse instead of continuing a comparatively useless pneumothorax.

The technic, indications and contraindications for intrapleural pneumolysis, as well as the selection of cases and end-results, have been covered in a previous contribution.[1] It was pointed out in a former communication that the cauterization of adhesions by the galvanocautery is objectionable because of the heat, smoke, pain and reaction to operation. Perhaps its greatest shortcoming is the character of the cutting produced because tissue is destroyed for a short distance around the cautery. Thus, blood vessels are severed without any previous obliteration, and unless a dull red heat is used, undue bleeding may occur. In addition to these reactions, if too much heat is used, there is also the danger of tissue necrosis occurring, which may involve the parenchyma of the lung, tuberculous cavities or tuberculous foci, thus liberating infection, or the necrosis may invade blood vessels and cause serious secondary hemorrhage. Furthermore, while the time required for the cautery to heat and cool after the current is thrown on or off is short, it nevertheless has its disadvantage, as occasionally a moment's delay, rendering the cutting instrument active or inactive, may result in serious consequences. Moreover, the shaft of the cautery sometimes becomes extremely hot and may cause a sloughing at the point where it passes through the thoracic wall. The hot cautery shaft may also damage lung

1. Matson, R. C.: Cauterization of Adhesions in Artificial Pneumothorax by the Jacobaeus-Unverricht Method of Closed Pneumolysis, Am. Rev. Tuberc. **19:** 233 (March) 1929.

tissue or the pericardium on which it may rest, during operation, unobserved by the operator who is giving his attention to the cutting alone.

All of these difficulties and dangers were serious, objectionable features which prevented successful results in many instances.

The successful utilization of electrosurgical methods in operations on the brain and in treatment for cancer stimulated much experimentation on our part to apply these methods to intrathoracic surgery, in an effort to lessen the difficulties and reduce the hazards incident to the use of the galvanocautery. We applied the electrothermic principle for the severing of adhesions, and as a result of its advantages over the galvanocautery, we are utilizing electrocoagulation and cutting in all cases presenting the difficuties that we have outlined.

During the utilization of this new principle over a period of the past two years, we have repeatedly performed operations by this method which would not have been attempted with the galvanocautery, and the comparative safety of the method over the galvanocautery procedure, with the results obtained, have created a strong conviction that the electrocoagulation and cutting will replace the galvanocautery. The application of the method intrathoracically, however, involves difficulty of control of bleeding not present in any open operation. While hemostasis in an open operation can be obtained by well known and easily applied surgical methods, it is obvious that these same procedures cannot be applied in such operations as the closed pneumolysis.

Aside from the anatomic relationship of large blood vessels and important nerve trunks to pleural adhesions or to the pericardium, it is of vital importance to know whether the adhesion to be cut contains blood vessels, compressed lung tissue, diseased foci or the prolongation of a cavity. Cutting into the prolongation of a cavity or compressed lung tissue is avoidable. Cutting into tuberculous foci in adhesions can be efficiently dealt with; but hemorrhage is one complication not always avoidable, and if it is at all profuse, it is a most unpleasant experience for the operator.

It is my prime purpose in this paper to discuss the utilization of electrosurgery for cutting adhesions in artificial pneumothorax by the closed method under thoracoscopic control, with especial reference to control of bleeding.

It is to be hoped that this paper will not encourage those without experience in this new branch of surgery to undertake too difficult operations at first, as the operation might result in failure and thus bring about unjust criticism of an otherwise valuable procedure. One sometimes hesitates, therefore, to describe a new technic, as it may make inexperienced operators too venturesome.

The usual source of bleeding during the process of cutting adhesions is from blood vessels collateral from the intercostals. One meets with

two types of vessels: those situated subpleurally, which can usually be detected by thoracoscopic examination and easily controlled, and those situated in the interior of adhesions, from which profuse bleeding occurs at times. In the case of the former, bleeding may be easily controlled by electrocoagulation; or, if the galvanocautery is used, before the blood vessels are cut they may be thrombosed by the application of the flat surface of the cautery. Dangerous bleeding, however, comes from blood vessels situated in the interior of adhesions, particularly in those which are dense and well organized. This dense type of adhesion is found in cases in which the patients have been subjected to prolonged and sometimes even short periods of pneumothorax treatment, particularly if the patient is of a fibroplastic constitution with a tendency for productive changes to take place in the tissues following pneumothorax treatment.

The latter type of vascular adhesion is more often found in the costovertebral gutter, at the apex of the lung and anteriorly near the costochondral junction. Densely organized adhesions in these areas should be approached cautiously because blood vessels of considerable size may be situated in their interior, the presence of which is not always possible of determination until they have been cut into.

Bleeding occurring during the cutting of cord and band adhesions, if the adhesions are not densely organized, usually stops after the adhesion has been cut through and the stump contracts. In well organized tissue, however, little retraction takes place, and bleeding may be a source of considerable anxiety to the surgeon. Therefore, it is obvious that the ideal method of severing adhesions must provide efficient hemostasis.

The objections to the galvanocautery in connection with hemostasis have already been pointed out. A detailed description of the physical characteristics of currents employed in electrosurgery will not be discussed. However, an understanding of the effects of the high frequency currents employed in the electrothermic method of cutting adhesions is necessary to apply this new procedure intelligently.

Briefly, the cutting effected by the electrothermic method is not a true cutting but a molecular disintegration of the tissues produced by a high frequency undamped current, an arc being formed at the point of contact between the tip of the electrode and the tissue.

It has been found that the form of high frequency electric current which results in the best cutting of tissue with least charring is that generated by the utilization of thermeonic tubes used in radio broadcasting, which give sustained oscillations of uniform amplitude at a rate of 600,000 per second. Even with an apparatus generating this form of current, it will show an impairment in cutting if the rate of oscillations is considerably increased or decreased. Based on this rate of oscillation, the theory is advanced that the cleavage of the tissue is accomplished not by mechanically cutting or by cauterization, but by a cellular disruption

resulting from the reaction of the cells to a sustained vibration transmitted at their own inherent vibration rate. The little sparking and resultant film of coagulation is secondary and subsequent to the cleavage of the tissue. Thus, two separate and distinct functions may be observed. One is the transmission by the operating electrode of the oscillations to cause cleavage, and the other is the slight sparking as the needle breaks contact with the parted tissue. If properly adjusted and handled, this results in a slight film or coagulation sufficient to check capillary bleeding but not sufficient to cause sloughing or charring with the danger of subsequent hemorrhage.

The ideal current for cutting, therefore, is recognized as that having a uniform sustained amplitude of 600,000 oscillations per second.

On the other hand, the best form of high frequency electric current for the generation of heat as used in coagulation is that having a damped oscillation of a long decrement. This current is generated from suitable apparatus containing spark gaps, condensers, etc. An apparatus properly designed delivering currents having long decrements will result in a clean blanching and dehydrating of the tissue when properly applied for coagulation, but apparatus of improper design may have a short decrement of the oscillating currents which will result in a brown or black burning of the tissue when applied for coagulation. The rate of oscillations of this form of current is usually about 1,250,000, but the rate of oscillation is not so important as the form of the trains or the decrement.

Two distinctly opposite forms of current are utilized in electrosurgery: One is ideal for cutting and the other for coagulating. To get the best results, it is essential to employ apparatus furnishing these two forms of current obtainable at the will of the operator and in the strength suited to the work. There are devices which will deliver cutting characteristics from a generator by means of a spark gap. This current, however, is a compromise between the two ideal currents and consists usually of a damped oscillation having short decrement and having the trains of oscillation crowded together. The peaks of the resultant current may simulate the oscillations of the undamped oscillations, but there are present the superimposed short oscillations which tend to cause undue heating when used for cutting. Similarly, this form of current even when differently adjusted is far from the ideal for coagulating. In practice, apparatus delivering the latter form of current is likely to be somewhat erratic and require adjustment from time to time in the course of operation. In other words, there is no assurance that it will respond to the requirements of the moment. In important surgical work, when hesitation, delay or trial cannot be tolerated, obviously nothing but the ideal currents for cutting and coagulation should be employed.

In our work, we have utilized the Wappler Wyeth Endotherm with special instruments which I have designed for intrathoracic use (fig. 1).

In the use of the coagulating current, a blunt electrode held in contact with the tissue and a small amount of current turned on will result, within a few seconds, in a blanching, dehydrating or coagulation in a circle around the blunt point. This will expand until the process near the point is carried to the degree of burning which would be manifested in a little sparking and by the formation of carbon. Obviously, it is desirable to stop before that state has arrived. On cutting through the center of this coagulated area with the operating electrode, it will be found that the depth of the coagulation is about equal to the radius. Thus, in using the blunt electrode, the area of the visible destruction may be used as a gage of its depth. Coagulation may be employed for hemostasis, if necessary, by clamping the tissue or vessel with the intrathoracic hemostat and switching on the coagulating current.

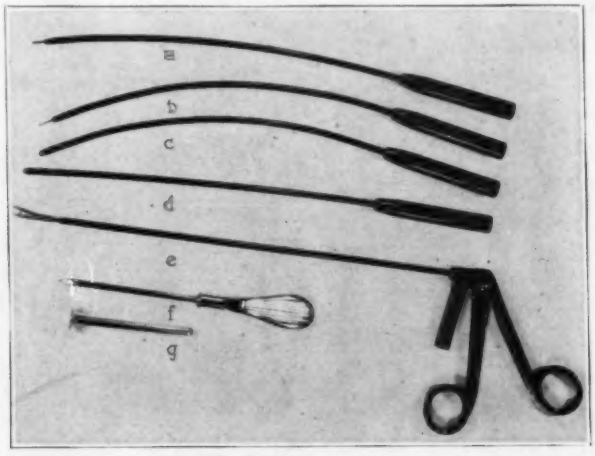

Fig. 1.—Author's instruments for the electrosurgical method of cutting adhesions: *a*, cutting electrode; *b*, pointed electrode for electrocoagulation; *c* and *d*, blunt electrodes for electrocoagulation; *e*, intrathoracic hemostat; *f*, trocar, and *g*, flexible cannula.

In the use of the cutting currents, considerable practice, first on meat and later on live animals should be exercised before an attempt is made to use them on the human body. In practice, it is best not to apply to the tissue to be cut more than a short portion of the operating electrode, the tip or only a few millimeters of the edge. If a larger portion is used, it will impair the cutting quality. Neither pressure nor traction should be used; in fact, this is objectionable. The operating electrode should be merely touched against the tissue, preferably at the point, and the action is that of following through the cleavage thus made. A little practice is required to get the sense of touch which is entirely different from that of traction or pressure of surgical cutting.

The amount of coagulation on the incision walls depends on the relation between the strength of the current employed and the speed of the passage of the electrode across the tissue. A little experimentation will soon teach the nature of the results expected. For example, with the cutting strength set at number 3 of the selective switch of a Wyeth Endotherm, an incision can be made at a fairly rapid rate without more than the film of coagulation, whereas hesitation or slow movement would result in charring. If slow movement is necessary, the cutting strength should be cut down to avoid charring. To make deep incisions, it is better to avoid attempts to make them with one stroke but rather to go over the same incision again using the point of the operating electrode and avoiding further contact with the tissue already parted. If bleeding spots show up after cutting by the proper current, the apparatus may be switched over to the coagulating current and the bleeding spot "touched up" with the operating electrode sufficiently to check the bleeding. In larger surfaces showing oozing of blood, the same current may be used. Increase in the strength and holding of the electrode at a slight distance from the tissue causing sparking to the tissue will result in sealing by surface coagulation. In case of more profuse bleeding, the blunt coagulating electrode or hemostat should be used as already referred to.

In our series of 130 cases of intrapleural pneumolysis, we have encountered three profuse hemorrhages. The first was encountered early in our experience. It occurred during a clinical demonstration of the cutting of adhesions with the galvanocautery, according to the method of Jacobaeus-Unverricht. The patient was unfit for such a demonstration as the operation was difficult, because there were many adhesions to be cut. Frequent interruption, caused by letting others view the work through the thoracoscope, markedly delayed the operation, which was being done cautiously with only a minimum heat in the cautery because of vascular adhesions. The patient's state of mind, as a result of conversation, made it necessary to speed up the work, whereupon the heat in the cautery was increased to a moderate cherry-red glow. All went well for a short time, when suddenly a gush of blood smeared the lens, obstructing all view. The thoracoscope was quickly withdrawn and wiped clean, but on reintroduction, the lens at once again became covered with blood. Knowing the exact site of the bleeding vessel, we were able to change the patient's position on the table so that blood no longer fouled the lens and the bleeding vessel could be clearly seen. The hemorrhage was eventually controlled by cauterizing tissue immediately surrounding the vessel and also by touching the vessel itself with the tip of the cautery. Two liters of blood were aspirated from the pneumothorax three days later. The patient suffered no inconvenience as a result of the accident, but the harrowing experience is yet so vivid in

the mind of the operator that he is convinced that this type of operation is not appropriate for clinical demonstration to groups. Demonstrations should be confined to a selected, interested few.

Two other hemorrhages occurred in our recent series, and while profuse for a moment, they were easily controlled by electrocoagulation.

In case 6557, a woman, aged 25, referred for pneumolysis, had been under pneumothorax treatment for nine months. Stereoscopic films showed an uncollapsed cavity in the upper lobe of the right lung suspended by a cord adhesion attached to the anterior end of the third rib and by two string and one band adhesion attached between the second and fourth ribs posteriorly in the costovertebral gutter.

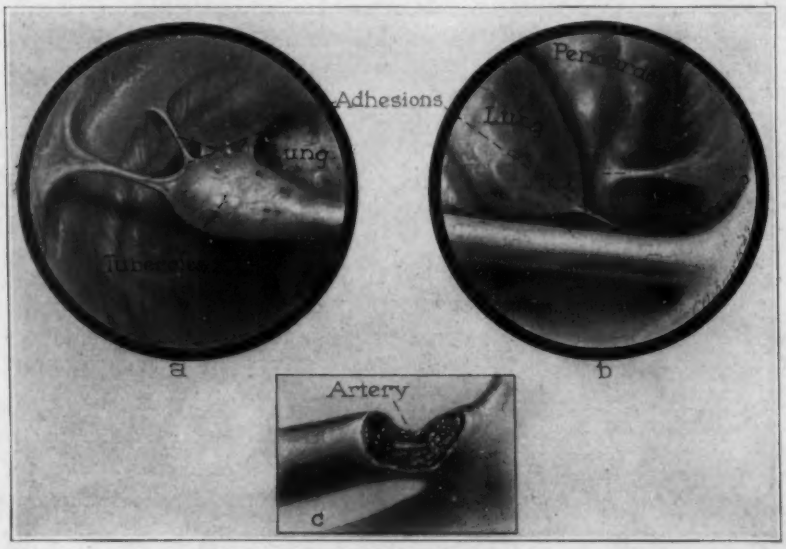

Fig. 2 (case 6557).—*a*, thoracoscopic view of cord and band adhesions attaching apex of the lung to costovertebral gutter; *b*, view of cord adhesion attached to anterior end of fourth rib, also adhesions between pericardium and chest wall and small string adhesions extending from the lung to the anterior chest wall and *c*, partially cut cord adhesion (shown in *b*) attached to the anterior end of fourth rib, showing site of blood vessel.

Thoracoscopic examination (fig. 2) confirmed these observations. The posterior adhesions were cut with the operating electrode after electrocoagulation and without anything unusual happening, as was expected. The cord adhesion anteriorly was then carefully studied. It was round, approximately 1 cm. in diameter (a minor affair from the standpoint of size alone). There were no blood vessels visible on its surface. It was densely organized and sensitive up to 3 cm. from the chest wall when all sensation disappeared. On slight coughing or clearing of the throat on the part of the patient, the adhesion increased

in diameter up to approximately 4 cm. from the chest wall, suggesting that it contained either the prolongation of a cavity or lung tissue, the former being suggested by previous stereoscopic film study. Pulsation of an expanding type was noted at the attachment of the adhesion to the chest wall, but not beyond 1 cm. from the chest wall. The pulsation was synchronous with the cardiac systole and not transmitted from the moving lung. A zone of electrocoagulation was made around the adhesion 2.5 cm. from the chest wall so as to avoid lung tissue and get as far away as possible from the chest wall.

The adhesion proved to be densely organized on cutting. Little contraction of the cut surface took place. Small blood channels were encountered as the cutting proceeded, which was always preceded by

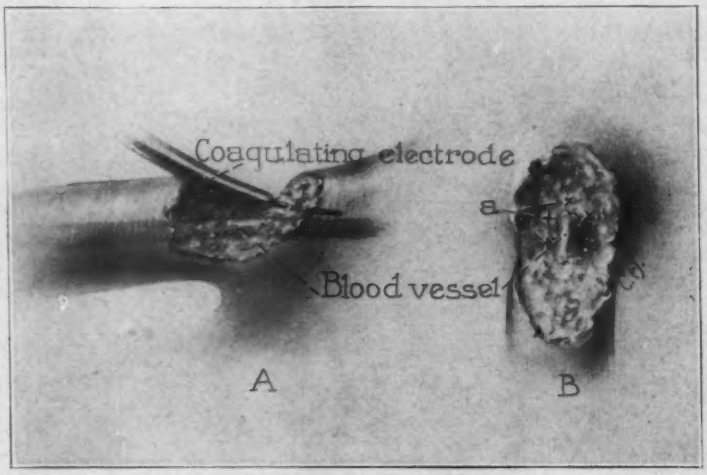

Fig. 3 (case 6557).—*A*, pointed electrode in position for deep coagulation of blood vessel and *B*, blood vessel for deep coagulation showing site of punctures (*a*).

electrocoagulation. Suddenly, near the center of the adhesion, a blood vessel was cut into which had not been obliterated by the electrocoagulation, no doubt because of the density of the tissue and because the electrocoagulation current was not sufficiently intense. A stream of blood was projected across the pneumothorax cavity to the lateral thoracic wall. The lens, fortunately, was so placed that it did not become smeared with blood. The author's blunt electrode was placed on the bleeding vessel. But electrocoagulation at this point only made matters worse as the bleeding became more profuse, whereupon the pointed electrode was introduced into the tissue close to the wall of the vessel and the coagulating current increased for depth; this controlled bleeding immediately (fig. 3). The adhesion was cut through without further loss of blood. The patient suffered no unfavorable result from the

bleeding. Two hundred and fifty cubic centimeters of blood was aspirated from the pneumothorax the following day. The operation was a complete clinical success.

I am certain that the hemorrhage in this case would have been a serious matter if we had been obliged to rely on the galvanocautery for control. As a matter of fact, I do not think we would have attempted cutting this adhesion with a galvanocautery.

Fig. 4 (case 6500).—Diagram showing distribution of adhesions between partially collapsed lung and chest wall as revealed by thoracoscopic examination.

In the third case, no. 6500, a woman, aged 24, referred for pneumolysis, had been under pneumothorax treatment for ten months. At first, the quantity of sputum became diminished and then remained stationary, averaging from 40 to 60 cc. in twenty-four hours during the last two months of pneumothorax treatment, when she also developed tuberculosis of the larynx and extension of disease to the opposite lung.

Stereoscopic films showed a large cavity in the upper lobe of the left lung. There were many band and cord adhesions attached posteriorly in the costovertebral gutter and to the dome of the pneumothorax cavity

above the first rib. There were several cord and band adhesions attached to the anterior end of the first, second and fourth ribs.

Thoracoscopic examination revealed conditions shown in figure 4. All of the adhesions were densely organized and contained numerous subpleural blood vessels. At the first operation, a large band adhesion attached to the anterior end of the fourth rib, as well as a band adhesion holding the lung to the aorta (fig. 5), and two string adhesions at the apex were cut. One of the latter was attached to the wall of the subclavian artery, while the other was attached 4 mm. from the vessel (fig. 6*a*). No bleeding occurred, hemostasis being perfectly controlled by electrocoagulation, and no reaction followed the operation.

At the second operation, two large band adhesions, one attached to the first intercostal space (fig. 6*b*) and the second to the third rib in

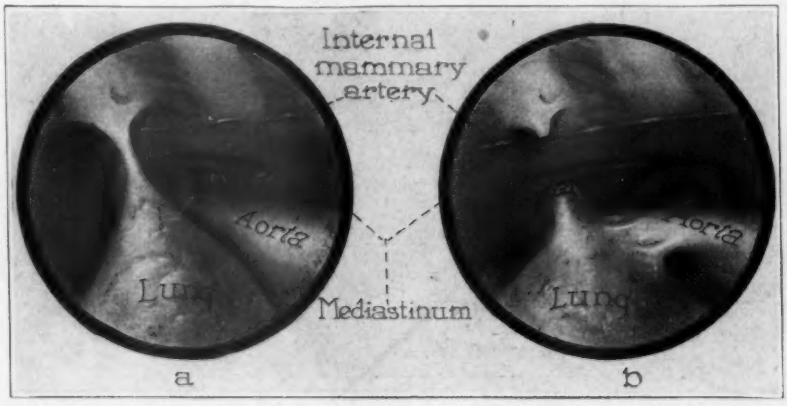

Fig. 5 (case 6500).—*a*, thoracoscopic view of band adhesion attached to anterior portion of second rib; *b*, view of same after cutting adhesion, showing band attached to the aorta.

the costovertebral gutter, were cut, again without bleeding or unfavorable complications.

At the third operation, two dense cord adhesions attached to the anterior end of the first and second ribs were cut. All of these operations were technically difficult, but bleeding was perfectly controlled by electrocoagulation, which alternated with the cutting. Following the operations, each of which was done at intervals of two weeks, an improved collapse of the lung was noted on stereoscopic films after each operation. The quantity of the patient's sputum was gradually reduced to 15 cc. as shown by daily measurement.

At the time of the previous operations, thoracoscopic study of the remaining adhesion showed that it was attached to the dome of the pneumothorax approximately 1 cm. distant from the subclavian artery just before this vessel crossed over the first rib. Furthermore, collateral

blood supply was seen emerging from beneath the subclavian artery and entering the base of the adhesion near its center. This collateral blood supply probably came from the arteria cervicalis profunda, which in this case may have been a branch of the subclavian artery instead of the costocervical trunk (fig. 7*a*). The adhesion was admittedly of a dangerous type, one we would not have considered cutting with the galvanocautery. Our success with electrosurgery, however, encouraged us to attempt it by the latter method, as the quantity of the patient's sputum had remained stationary at 15 cc. daily, and both stereoscopic film study and thoracoscopic study showed the remaining adhesion to be of great technical importance. Undoubtedly a satisfactory collapse of the lung (on which the patient's recovery depended) would not be obtained until it was severed.

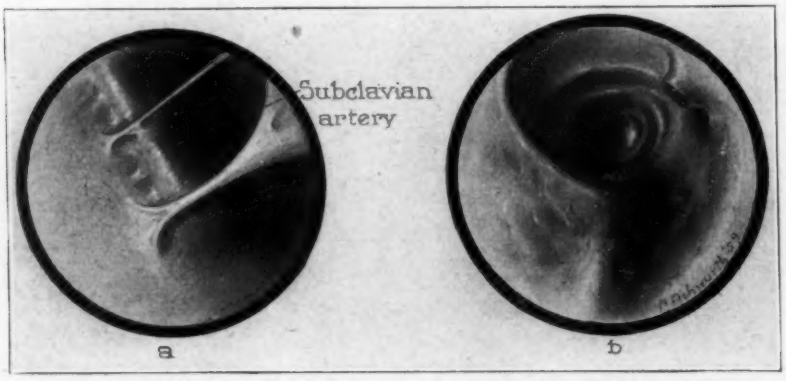

Fig. 6 (case 6500).—*a*, thoracoscopic view of two string adhesions extending from apex of the lung to the dome of the pneumothorax. One is attached to the parietal pleura covering the subclavian artery and the other is attached 4 mm. from the vessel; *b*, band adhesion shown in roentgenogram after cutting with endotherm.

The band was therefore carefully electrocoagulated on its outer surface, but because of its position, it was impossible to study its inner surface or put an electrode in a position to do an electrocoagulation of that surface. A line of electrocoagulation was made 2 cm. from the chest wall on the outer surface, and cutting followed with the undamped current, of moderate intensity, first, from the posterior edge toward the center and then from the anterior edge toward the center. As the center of the adhesion was approached from either side, the band was found to be more and more densely organized with tough bands of fibrous tissue between which were numerous blood channels. Owing to the dense character of the tissue, little retraction of the cut surface took place, and it was constantly necessary to resort to the coagulating current to control bleeding. On further approaching the site of the collateral blood supply,

after cutting through a particularly dense band of fibrous tissue, a sudden profuse hemorrhage took place. For a time it seemed uncontrollable, and preparations were made for blood transfusion and thoracotomy for the purpose of placing a clamp directly on the bleeding vessel. Fortunately, just at the moment when failure to control bleeding seemed imminent and no further time was to be wasted by attempting to control it with electrocoagulation currents, the method of puncturing around the blood vessel and doing a deep coagulation proved successful, and all bleeding stopped.

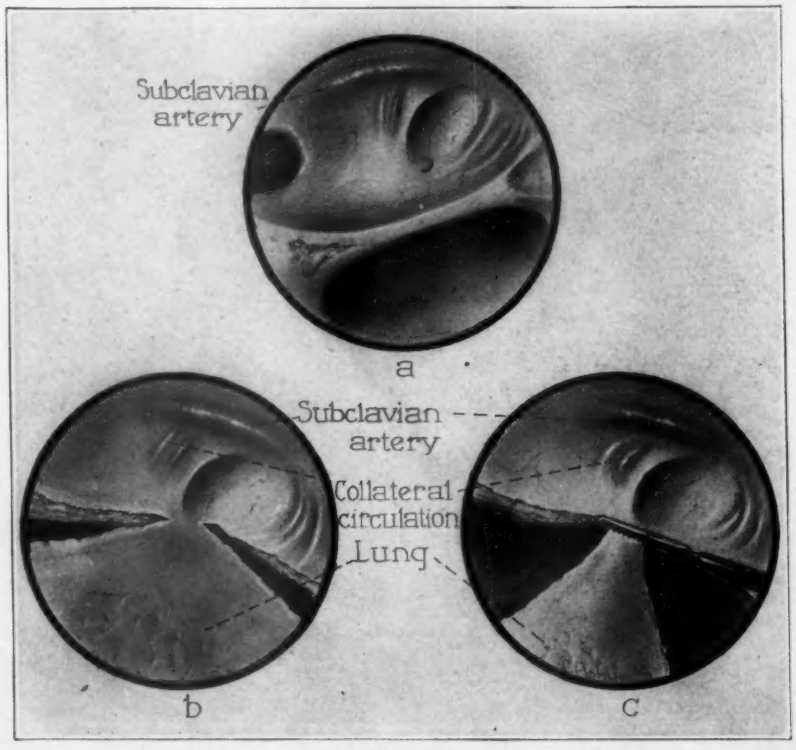

Fig. 7 (case 6500).—*a*, thoracoscopic view of apical adhesion; *b*, same adhesion partially cut; *c*, intrathoracic hemostat clamped on vascular remains of adhesion for purpose of electrocoagulation before cutting.

It seemed reasonably certain that the vessel had not been severed but only cut into, and that the remaining portion of adhesion contained other blood vessels of a dangerous size. Lack of confidence in being able to control bleeding prompted us not to attempt further operation, at least until some more certain method of hemostasis could be developed.

The patient suffered no unfavorable symptoms as a result of the hemorrhage, except a slight febrile reaction which lasted three days. The pneumothorax cavity was filled with carbon dioxide gas, and the intra-

pleural pressure was considerably increased over former inflations. Forty-eight hours after operation, 400 cc. of bloody exudate was aspirated.

The quantity of the patient's sputum remained unchanged by the operation, as was expected, and for four weeks following operation, the daily quantity of sputum remained 15 cc. Anticipating such a course and convinced that a method must be found for cutting the offending band without danger of hemorrhage, I devised an intrathoracic hemostat which

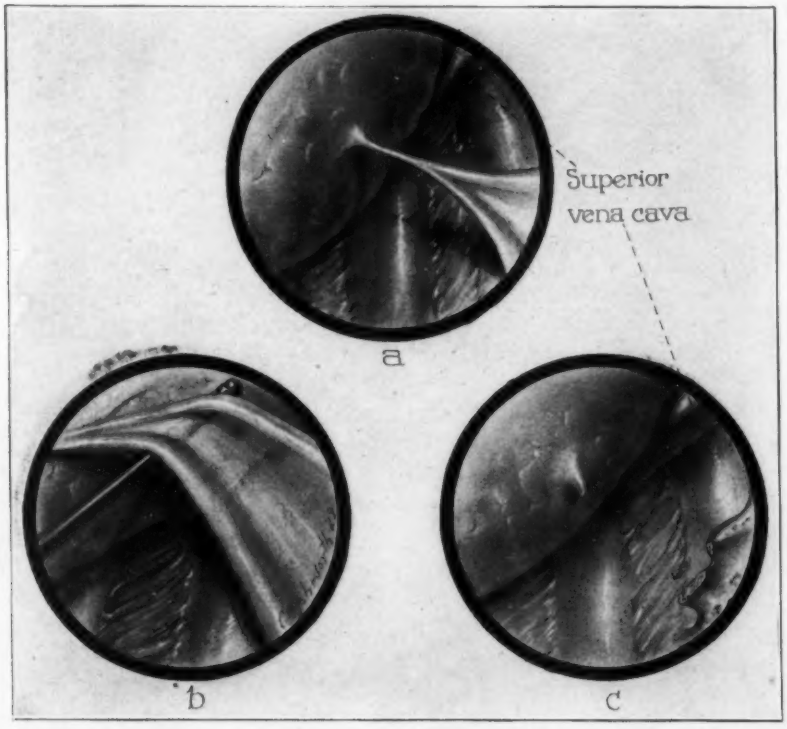

Fig. 8 (case 6172).—*a*, thoracoscopic view of a string adhesion, 5 mm. wide extending from the upper lobe of the right lung near the interlobar fissure to the lateral chest wall; *b*, method of examining structure of adhesion with author's blunt electrode; *c*, view of adhesion after cutting showing retraction of stumps.

was insulated so as to throw the coagulating current to the jaws of the hemostat. After the instrument was tested with satisfactory results, the final operation was decided on.

The thoracoscope was introduced in the first intercostal space midclavicular line. A superb view of the remaining uncut band was seen (fig. 7*b*). The collateral blood supply was seen as on previous examination. The adhesion had every indication of extreme vascularity. There was no necrosis at the site of previous cutting, and the cut surface was

clean. The intrathoracic hemostat was introduced in the third intercostal space midaxillary line and its jaws clamped down on the remaining portion of the adhesion which was then thoroughly electrocoagulated (fig. 7*c*). Cutting was then carried out without any loss of blood, no further electrocoagulation being necessary. Complete collapse of the lung followed.

The quantity of the patient's sputum promptly diminished, so that after two weeks the daily quantity ranged from 0 to 3 cc. During the course of these operations, a progressive improvement also took place in the opposite lung and larynx.

Fig. 9 (case 6489).—Thoracoscopic view of adhesion attached to anterior mesial aspects of chest wall and mediastinum and reflected over the aorta, after having been almost completely cut through.

The danger of thrombosis of the vessel from heat of the galvanocautery and inflammatory reactions, as well as sloughing of tissue, has been pointed out in connection with cutting adhesions situated close to large blood vessels. In numerous cases, we have cut adhesions so situated which would not have been attempted with the galvanocautery. The following cases illustrate the value of electrosurgery in such cases.

In figure 8 (case 6172) is shown a thoracoscopic view of the apex of the right lung showing a fan-shaped adhesion extending from the apex of the lung to just above the sternal end of the first rib. The superior vena cava was 2.5 cm. distant from the point where the adhesion should be cut. In this case, some sudden unexpected movement

or coughing paroxysm on the part of the patient could easily have resulted in damage with a heated galvanocautery so close to a large blood vessel, for in spite of shutting off the current at the time the unexpected act was committed, the cautery could still remain sufficiently hot to do damage, whereas with the endotherm the instant the current is off, it is inactive and incapable of doing damage.

Figure 9 (case 6489) shows a thoracoscopic view of a dense band adhesion with its base attached to the anterior mesial aspects of the pneumothorax cavity and reflected over the aorta to which it was attached, showing cutting effected by the endotherm after electrocoagulation. This operation was executed without the loss of blood, and while extensive, it was not followed by inflammatory reaction on the part of the pleura. Complete collapse of the lung followed, and the patient's convalescence was uneventful.

In this case the operation was extremely difficult and prolonged, and without electrosurgery it would have been impossible to carry it out safely. It could not have been done with the galvanocautery except at a great risk.

COMMENT

1. Intrapleural pneumolysis is an operation of great utility. When it is properly done it is not dangerous and will convert a useless pneumothorax into an efficient one, thus saving the patient from thoracoplasty.

2. My experience with the electrosurgical method has given me confidence in this method of cutting adhesions. Control of bleeding is the most dangerous problem and requires thorough knowledge of the character of the currents used. Electrosurgical cutting is accomplished without heat or smoke to disturb the view. There is a minimum of tissue reaction afterward, and while more complicated and technically more difficult than the galvanocautery method, it is without doubt a notable advance in this branch of surgery, which is being more widely employed.

3. Intrapleural pneumolysis by the closed method is not a fool-proof procedure with either the galvanocautery or the electrothermic method. The operator must be familiar with the appearance of the pleural cavity and at all times perfectly orientated regarding the nature of tissue to be cut. This training in the use of the thoracoscope in the pleural cavity is just as important to the surgeon or phthisiotherapeutist as a thorough knowledge of the cystoscopic image is to the urological surgeon. The operator should have experience with pneumothorax and must have surgical training.

Acknowledgment is due Mrs. Henry F. Chaney, who, by a grant to the Portland Open Air Sanatorium, aided in this work.

THERAPEUTIC PULMONARY COLLAPSE

DEAN B. COLE, M.D.
AND
FRANK S. JOHNS, M.D.
RICHMOND, VA.

With the exception of lobectomy, surgical intervention in the treatment for pulmonary tuberculosis and many other diseases of the lung has as its objective compression of the lung in part or as a whole. This is done, first, to rest the lung and aid the blood and lymph streams in handling the infection and thus to promote both absorption and scar tissue formation; second, for the obliteration of cavities, lessening infection, absorption and degenerative changes and also to eliminate the danger of hemorrhage through rupture of a blood vessel in a cavity; third, for the promotion of drainage by partial compression of cavities or bronchiectatic sacculation.

Every patient considered for pulmonary collapse must be studied carefully by both internist and surgeon, and a definite plan outlined. We believe all collapse to be selective, and that the judgment used in selection of patients, the type of collapse, time of operation and amount of compression will largely determine the results. Since we no longer believe that complete compression is necessary or even desirable, we attempt in all instances to determine the optimum therapeutic collapse.

For simplicity and convenience, we have divided our consideration of surgical collapse therapy into three distinct procedures. Artificial pneumothorax which includes the first and largest group of our cases will be considered as a surgical procedure, to differentiate collapse therapy from the usual medical routine.

PNEUMOTHORAX

Our experience with pneumothorax extends over a period of more than eleven years, while thoracoplasty, phrenicotomy, phrenic avulsion and other methods of surgical intervention were begun five years ago. We have experienced the usual successes, failures and complications. Patients with advanced disease have constituted the bulk of our failures with pneumothorax, and have furnished much of the material for phrenicectomy and thoracoplasty. Incidentally, with this group we have had the most complications, such as pleurisy with effusion, empyema, pleural shock and air embolus. During this period our patients have been grouped as follows: (1) patients referred from various sanatoriums for study and, when advisable, for surgical treatment; (2)

those seen in routine consultation of private practice; (3) patients from the municipal tuberculosis sanatorium at Richmond, and (4) patients admitted to the medical and surgical services of the Medical College of Virginia. Through these connections it has been our privilege to study a fairly large group.

In patients with moderately advanced pulmonary tuberculosis, pneumothorax has been used with favorable results and fewer complications. Many patients who are not responding satisfactorily to medical treatment improve rapidly when pneumothorax is instituted, and within a short time are able to return to their homes, resuming former occupations while continuing pneumothorax. We have grown bolder about the contralateral lung, not only with pneumothorax but with other surgical procedures. If the process in the contralateral lung is of the exudative type, we prefer to observe the patient until this has absorbed or fibrosis has taken place. Should the necessity for collapse seem sufficiently urgent, we sometimes institute pneumothorax even when there is a moderate amount of tuberculous infection of the exudative type in the contralateral lung. We are instituting pneumothorax earlier in the course of the disease and in a greater percentage of patients, and feel that in many with moderately advanced tuberculosis there is or has been an optimum time for pneumothorax therapy. When we encounter the patient with a hopelessly advanced condition pleading for an operation, we are convinced that many, if not most of them, were at some previous time suitable for pneumothorax, or other form of collapse therapy, probably when the disease was in the moderately advanced stage.

Tuberculous Pneumonia or Acute Exudative Tuberculosis.—In 1921, we first used pneumothorax in a patient with tuberculous pneumonia, the pneumonia following a profuse pulmonary hemorrhage. Prior to hemorrhage, this patient had a minimal tuberculosis. Pneumothorax was refused for control of bleeding, but consented to after the development of tuberculous pneumonia of the entire right lung. The lung was collapsed, and the patient recovered. Since then we have been collapsing the lung in these cases and using pneumothorax wherever possible in the acute exudative type of pulmonary tuberculosis. Of thirty patients with this acute type of process in whom pneumothorax was attempted, fourteen are apparently well and able to work; ten have partially recovered, and six have died. Of the ten who partially recovered, collapse was entirely satisfactory for five. Five developed fluid; three of these, tuberculous empyema. One patient with a bilateral process developed fluid, and later empyema. Thoracoplasty was done, and although the patient is still in a sanatorium, she is free from symptoms and the good lung has healed. Another patient who had the right lung collapsed for more than two years developed pneumonia throughout the left lung so that it

was necessary to withdraw air from the collapsed side and compress the pneumonic lung. Pneumothorax did not check the spread of tuberculosis in the pneumonic lung, and the patient had a spontaneous rupture followed by tuberculous empyema. By persisting with closed drainage,

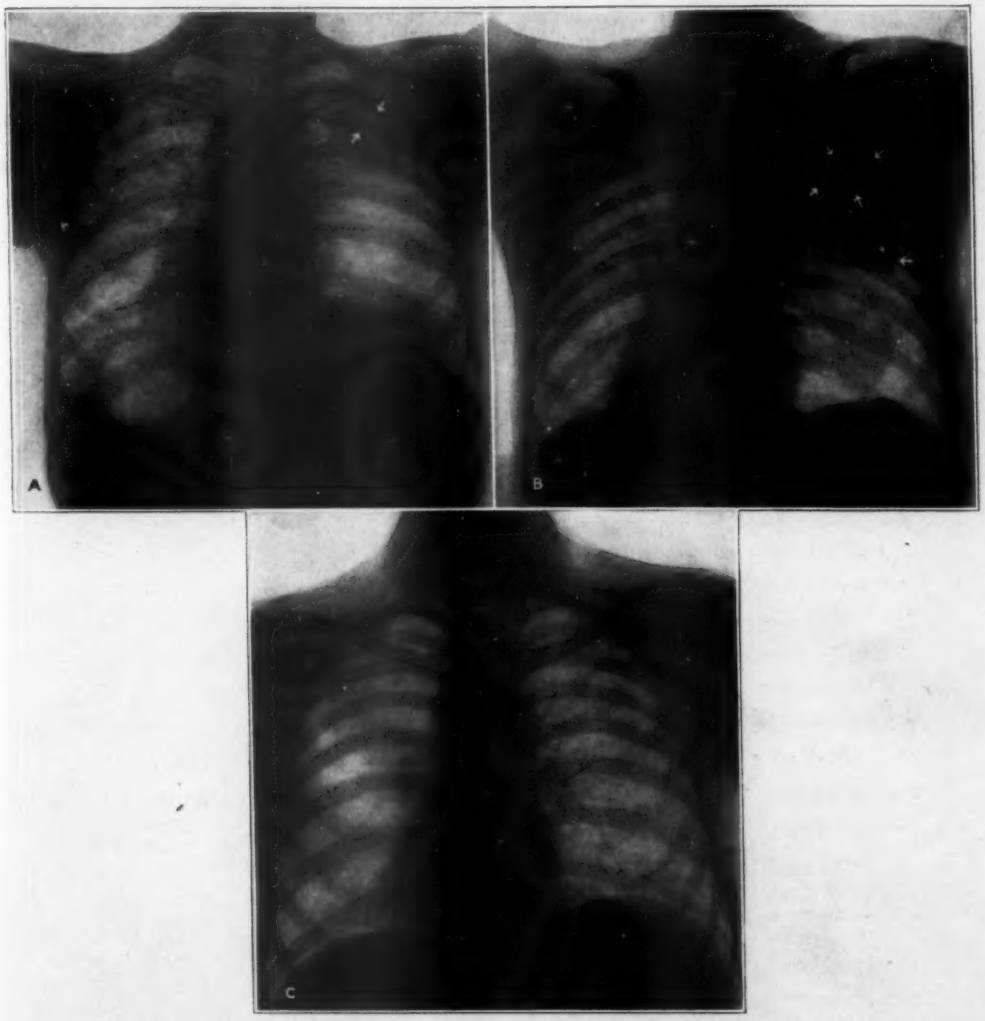

Fig. 1.—*A* shows acute peripheral abscess of the lung which has not responded to suitable forms of treatment; *B*, the lungs of the same patient after selective pneumothorax; *C*, reexpansion of the lung, just before pneumothorax was discontinued. The patient has remained clinically well.

we were able to clear up the empyema and later permitted the lung to reexpand. Multiple adhesions developed, including pleuropericardial and diaphragmatic, causing severe cardiorespiratory symptoms. Phrenic

avulsion was done giving immediate and complete symptomatic relief, but we believe that thoracoplasty will be necessary. In three patients with acute exudative tuberculosis, where collapse was ideal, the condition continued to spread and cavitate, and all the patients died.

Abscess of the Lung.—Fifteen patients with acute abscess of the lung have been successfully treated with pneumothorax. When this treatment was first begun we made the mistake of giving too much air, which hampered drainage and temporarily did harm. However, as soon as this was discovered sufficient air was aspirated to reestablish drainage, and the patients did well. Small quantities of air, never more than from 50 to 150 cc., should be given at frequent intervals, daily or on alternate days. There is no necessity or advantage in attempting to collapse the abscess cavity. A small amount of compression is sufficient to stimulate drainage and discourage further spread of the abscess.

We keep all patients with acute abscess of the lung at absolute rest in bed, using postural drainage several times daily. Bronchoscopies, vaccines and other measures are used as indicated. Nearly all acute abscesses of the lung will clear up when treated in this manner without the use of pneumothorax, but we find a few patients in whom pneumothorax is most helpful. One patient, treated with postural drainage and bronchoscopy, who was not responding, was given small injections of air daily with immediate improvement, becoming free from fever on the third day. No patient with a basal peripheral abscess of the lung has been given pneumothorax, but peripheral abscesses in the upper half of the lung have shown equally as good response as those in the hilar area.

We feel that pneumothorax is both unsatisfactory and unsafe in the treatment for chronic abscess of the lung. Two patients with chronic abscess died after pneumothorax, and in other patients treated in this manner results were unsatisfactory. We have abandoned the use of pneumothorax in such cases.

In the obliteration of empyema cavities or the collapsing of the chest for relief of symptoms from adhesions causing mediastinal or cardiac symptoms, or symptoms from pleural retraction or bleeding from excessive scar tissue formation, pneumothorax has no place, and other surgical procedures must be utilized.

Management of Patients on Whom Pneumothorax is Instituted.—Pneumothorax is instituted in the hospital or sanatorium and never at home unless in case of hemorrhage or other extreme emergency. All sick patients are kept at rest, and after pneumothorax they must remain in bed for a minimum of two months after becoming free from symptoms. Small quantities of air, from 100 to 300 cc., are given at frequent intervals with a small needle, from 20 to 23 gage, of necessary length.

A larger needle is never used unless fluid or pus is to be aspirated. When deflating a lung for the first time, sufficient warm physiologic solution of sodium chloride is used to separate the pleural surfaces. In this way injury to the visceral pleura is avoided, and a satisfactory manometer reading obtained without trauma. After pneumothorax, patients are followed up closely. Routine fluoroscopic examinations are done prior to every refill and roentgen examination made whenever indicated.

Complications we have encountered are empyema, pleural effusion, pleural shock and air embolus. We formerly had fluid to develop in approximately 50 per cent of all our patients after pneumothorax. In the last three or four years we have had less difficulty with fluid forma-

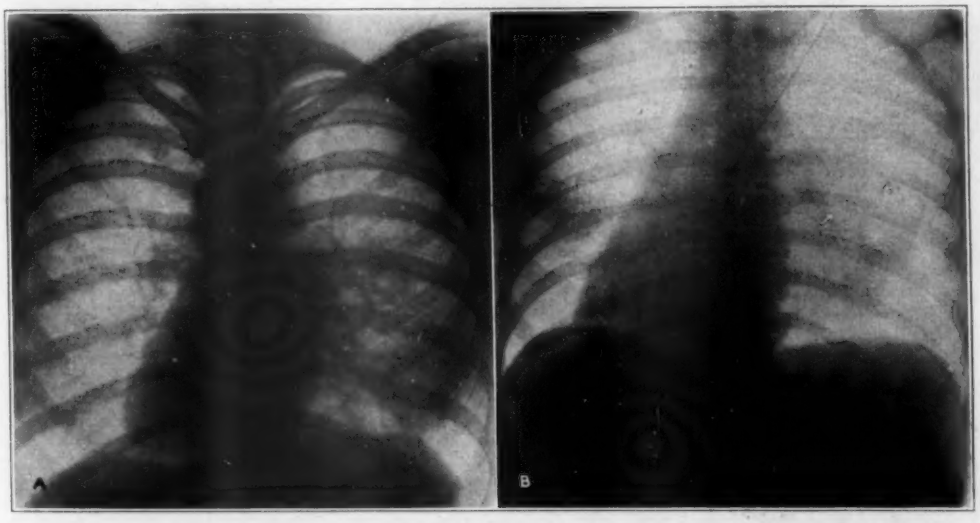

Fig. 2.—*A* shows acute exudative tuberculosis. The sputum was loaded with tubercle bacilli and showed but few other organisms. *B*, taken after selective pneumothorax, shows basal collapse of tuberculous pneumonia on the right and mediastinal shifting producing partial compression of the pneumonic area at the base of the left lung.

tion, and now we encounter this in not more than 15 per cent of these cases. Empyema is a less frequent complication, but we believe that there is a small percentage of cases in which the development of empyema is inevitable. The better results in handling these complications and their less frequent occurrence we attribute to more careful selection of patients for pneumothorax; we are not using it as often in the patient with an advanced hopeless condition, thereby minimizing the stretching, tearing and other injuries here encountered. Small quantities of air are given at shorter intervals with less change of interpleural pressure, using a smaller needle, for less injury to the pleura. Patients developing effu-

sion after pneumothorax are put to bed, and, as in all cases of pleurisy with effusion, fluid is withdrawn and replaced by air. Should empyema develop, this is treated in the same manner using physiologic solution of sodium chloride and other irrigations. Thoracoplasty is not used in these cases until the more conservative measures have failed. On those patients who have not had previous treatment with pneumothorax, this is continued until fluid ceases to form. The lung is then permitted almost to reexpand, and from symptoms, physical signs, roentgen and fluoroscopic examination a decision is reached as to whether to continue with pneumothorax or permit the lung to reexpand. Pleural effusion has been attributed to calcium deficiency, salt retention, alkalosis, weak heart and low blood pressure, but we have been unable to see any direct relationship between these conditions and fluid formation. We believe infection, irritation and trauma to be the causative factors.

Symptoms attributed to pleural shock have been encountered in a number of instances, but are usually mild and promptly subside. In a few instances symptoms have been more severe. We have noticed that patients who suffer from pleural shock usually complain of pain even when the skin is being anesthetized. One patient with basal tuberculosis, treated with pneumothorax, complained of severe pain in the chest and neck the first time the needle was introduced. The pain grew worse with each succeeding deflation until pneumothorax was finally abandoned. At the last deflation, the patient was given a hypodermic injection of morphine and atropine to lessen the shock, but when the needle touched the parietal pleura, the patient screamed because of excruciating pain in the chest and neck. Both phrenic avulsion and thoracoplasty were done with the patient under ethylene anesthesia, and a normal reaction followed. Another patient with tuberculous pneumonia, on whom pneumothorax was started in September, 1926, received refills at regular intervals without pain or other evidence of reaction until the following December. After a refill of 200 cc. of air had been given the patient complained of symptoms which were attributed to mild pleural shock. At that time the patient had a uniform collapse of approximately 75 per cent without adhesions and otherwise entirely satisfactory. Symptoms subsided within a few minutes and the patient continued to be free from them until Jan. 25, 1927, when on the introduction of the pneumothorax needle, the patient screamed because of pain in the chest, shoulder and neck, and ceased to breathe. The needle had just reached the parietal pleura and no air had been given or even an attempt made to get a manometer reading. The patient's heart continued to beat regularly and otherwise normally under artificial respiration for thirty minutes, but we were never able to get her to breathe voluntarily, and she died in less than an hour. Autopsy was refused.

Air Embolus.—A patient with advanced tuberculosis and many adhesions was successfully treated with pneumothorax from May, 1926, to January, 1927. Following a refill of air on January 15, the patient suddenly complained of depression followed by a tingling sensation in the arms and hands, blindness coming on within a few seconds. The pulse became exceedingly slow, and the patient was unconscious in less than two minutes. The needle, having been withdrawn before the onset of symptoms, was reinserted and a marked negative manometer reading was noted, although pressure just previously was —2. One hundred cubic centimeters of air was aspirated, and the patient recovered consciousness within a few hours, but sight and sensation did not return for

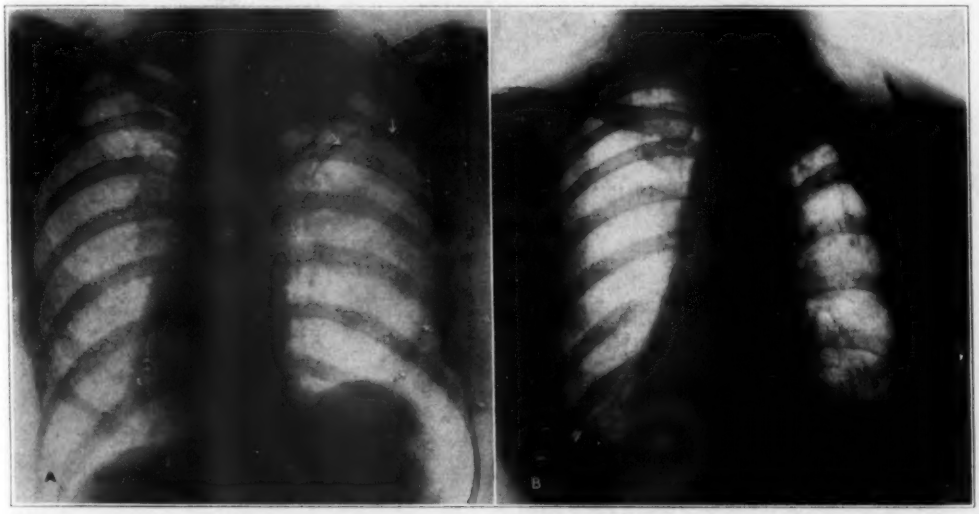

Fig. 3.—*A* shows tuberculous infiltration in both lungs and numerous cavities; *B* was taken three years after complete but selective thoracoplasty. Due to extensive involvement of the contralateral lung, more complete compression seemed then inadvisable.

twenty-four hours. One week later, during a refill of pneumothorax, the same symptoms occurred in a milder form. At this time, counting with the aid of a stethoscope, the heart rate was only seven beats per minute. Pneumothorax was abandoned.

Another patient, an old man with chronic abscess of the lung, suddenly died on the introduction of the needle. Respiration and the heart beat stopped almost simultaneously; we believe that death was due to cardiac failure and not to either air embolus or pleural shock. The accidents in these four patients are discussed somewhat in detail as we believe there is a difference in air embolus, pleural shock and cardiac failure, any of which may happen in pneumothorax treatment.

PHRENIC AVULSION

The second group in this study of surgical collapse consists of cases in which phrenic avulsion has been employed. Our series includes only eighteen cases of this type. But in reviewing even so small a series, certain phases regarding the use and value of surgical procedures on the phrenic nerve are worthy of emphasis. All of our cases of phrenic avulsion, with one exception, have been done under local anesthesia. We have attempted to remove from 6 to 10 cm. of the phrenic nerve; and have used both types of incision. In our first cases we followed the posterior border of the sternomastoid which gave a satisfactory exposure but a rather prominent scar. In the greater number of cases in the series an incision has been made about 3.5 cm. long just above and parallel to the clavicle. This has been found to give adequate exposure with a less noticeable scar. Granted a thorough knowledge of the anatomy in this region, little difficulty should be experienced during the procedure. It is fair to say, however, that this operation on an obese, short-necked patient will cause the surgeon a certain amount of mental anguish, while on a thin patient it will seem much easier. This, however, is true of all surgical conditions.

Reported injuries should be kept in mind. We have, fortunately, had no complication with the operation. The thoracic duct has never been exposed, nor has any damage to other structures been experienced. Infection of the wound has not occurred. A number of failures from operation on the phrenic nerve have been reported. Following carefully the work of Felex, we have made it a practice to note the size of the true phrenic nerve as each operation, and if there is any question about its size, we always make an effort to get the accessory phrenic as well. The anomaly is reported to occur in from 20 to 30 per cent of such cases. After phrenic avulsion, we have followed every case closely. Our first operation of this type was done five years ago. No patient has been made worse by the operation.

Clinical results supported by fluoroscopic studies have shown that our desired aim is attained by this operation. The diaphragm is paralyzed, with noticeable elevation, the latter depending on the present degree of adhesions. Beneficial results following this lesser procedure have been beyond our expectations, and we feel that it has a distinct and valuable place in one's armamentarium for therapeutic pulmonary collapse.

One of the most difficult conditions that comes into our clinic is bronchiectasis. Following the conservative school in a number of these cases, we have given relief by compressing the lung by means of phrenic avulsion, plus resection of the ribs. We realize that comparatively little support has been given the therapy of paralyzing the diaphragm as a treatment for bronchiectasis, and we wish to report favorable results in

selective cases by phrenic avulsion and postural drainage. Patients having a limited involvement closely associated with the diaphragm have shown distinct improvement, and many of them believe that they are well, although this optimism should not be overestimated. Clinically, they are markedly benefited. Any lesser operation which carries little hazard and offers improvement is worthy of consideration.

THORACOPLASTY

In the less fortunate patients with more extensive involvement. thoracoplsty in two or more stages, as advocated by Hedblom and others, has been our procedure. This type of operation may not produce a complete cure, but it has certain commendable features. The mortality of the operation is not a deterrent factor if it is carried out in stages.

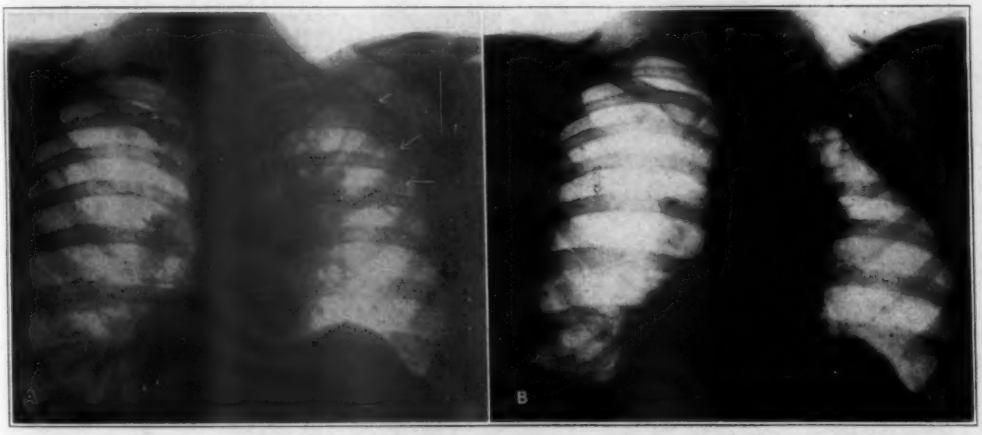

Fig. 4.—*A* shows advanced bilateral tuberculosis with a large apical cavity which grew larger in spite of the patient resting for months in bed. The remainder of the lung shows the tuberculous lesions mostly healed. *B* was taken after selective thoracoplasty with obliteration of the cavity. The patient is now clinically well and symptom-free.

Every one of our patients of this type has shown improvement sufficient to justify return to previous occupation.

Pneumothorax has been tried in bronchiectasis with poor success. Since the advent of iodized oil and lung mapping, we have discontinued the use of pneumothorax in these cases even for diagnostic purposes.

Thoracoplasty as a means of producing pulmonary collapse in tuberculosis is a procedure well established in this body. Fifty-one patients with pulmonary tuberculosis have been subjected to this operation in our practice. A few were not given the complete standard procedure. In certain cases, a selective collapse was directed at the advanced pathologic process. Resection of the upper five ribs only was done on five of these

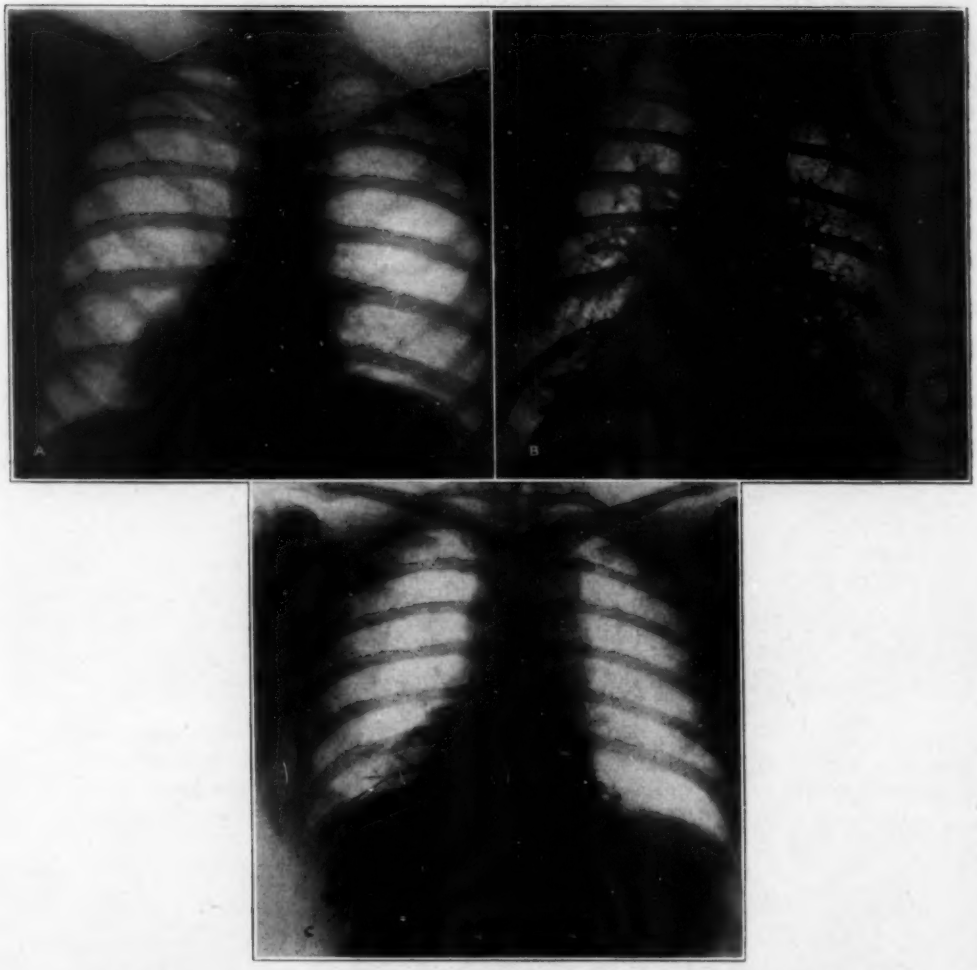

Fig. 5.—*A* shows basal râles, principally small and medium moist râles, at the left base posteriorly. A clinical diagnosis of bronchiectasis of the base of the left lung was made. *B*, taken following the introduction of iodized oil, shows bronchiectatic pockets just above the diaphragm, principally behind the heart shadow on the left. *C* was taken following phrenicectomy. The patient has had subsequent injections of iodized oil and has remained practically symptom-free. Her condition has been diagnosed as tuberculosis for nineteen years prior to our study.

patients, all of whom had additional involvement of the so-called "good lung." The first patient of this type was a poor risk, who was eager to take a chance for improvement. With some reluctance we resected the upper five ribs, expecting to complete the operation at a later period. Following the apical collapse, her condition improved so rapidly that she refused to have the complete operation.

No ill effects have followed this procedure. There has not been any extension of infection to the lower lobes, which has been reported as one of the contraindications to resecting the upper ribs first. On the other hand, it may be argued that an upper thoracoplasty is better borne by the patient than a resection of the lower ribs. In spite of the fact that resection of the first rib is the only difficult part of the operation, we feel that compression produced by apical collapse is the most important therapy, because it is directed at the root of the pathologic process. Furthermore, the better part of the lung is allowed to function and aid in expectoration. Resection of the lower ribs not infrequently causes cardiac embarrassment through its influence on the great vessels. The accumulated evidence seems to prove that resection of the upper ribs causes less reaction and is less hazardous to the patient. With our earlier cases in which we followed rather closely Sauerbruch's plan of operating, there was usually considerable reaction to the first stage of the operation, with a slighter reaction after the second stage. The disturbing post-operative course of these cases, plus the recommendation of Alexander, has influenced us to use phrenicotomy with an upper thoracoplasty. While this might not be suitable for all cases, especially if there is involvement of the lower lobe, we have had equally good results with a lesser amount of surgical intervention, which we believe to be sound reasoning.

SUMMARY

Briefly summarizing our conclusions from the foregoing fairly extensive study of therapeutic pulmonary collapse, we find that surgical collapse is rendered complete only by utilizing all our resources. These include: the carefully modified uses of artificial pneumothorax; phrenic avulsion and thoracoplasty, emphasizing the virtue of primary resection of the upper ribs. We believe that such selective collapse should receive foremost consideration. Careful choice of the type of collapse suitable for the individual case is of paramount importance, for no standard operation can be applied routinely to surgical pulmonary pathologic processes.

ABSTRACT OF DISCUSSION

ON PAPERS BY DRS. LILIENTHAL, WELLES, MATSON, AND COLE AND JOHNS

DR. EDWARD S. WELLES, Saranac Lake, N. Y. I should like to express my appreciation of Dr. Matson's paper, and I should like to add to Dr. Matson's argument for that procedure.

Five or six years ago, Dr. Jacobeus came over to this country and demonstrated the method at several tuberculosis centers, but nobody seemed to like it. We did not take it up at Saranac Lake; the medical men there did not want it done. They were all afraid of hemorrhage as Dr. Matson says, because the view through the instrument was not sufficient to make the procedure safe.

About two years ago Dr. Matson came to Saranac Lake and demonstrated the same thing to us, except with the Unverricht instrument, and convinced all the phthisiologists of its value. They wanted me to use the operation; so I secured the outfit and have been doing it since.

I have used this procedure in from thirty to thirty-five cases now, nowhere near the number that Dr. Matson has, but a sufficient number of times to make me enthusiastic about it. I do not believe that it is being used enough throughout the country in the other tuberculosis centers. So far, I have had no bad luck with it. I have never had a serious hemorrhage, and of all the cases, I have had only one case of empyema.

I think that we are overlooking a valuable aid in the treatment for tuberculosis by not using this method because of possible imagined objections to it. It is difficult to do, and it takes a good deal of practice to be able to do it well, to localize oneself accurately in the chest and to learn how to handle the cautery with safety, but it can be done. It is not any harder to learn than cystoscopy, and I think that it is just as valuable in its field.

I think that Dr. Matson deserves a great deal of credit for the presentation of the subject.

DR. RALPH C. MATSON, Portland, Ore.: I regret that phthisiotherapists and thoracic surgeons in general do not appreciate to the extent justified the value of intrapleural pneumolysis by the closed method.

The phthisiotherapist is appreciating more and more the value of phrenic neurectomy and thoracoplasty and is more frequently referring these cases to the thoracic surgeon. The phthisiotherapist too often is guilty of continuing an unsatisfactory pneumothorax until the patient's condition is so hopelessly advanced that other operative measures cannot be utilized. This group of cases embraces about half of the pneumothorax group and therefore represents a large number of cases in which the patients could be benefited by other forms of collapse therapy, and one should especially consider an intrapleural pneumolysis first because if successfully carried out, the patient is spared from a thoracoplasty.

The phthisiotherapist needs education regarding the value of the entire group of surgical collapse procedures.

THE EFFECTS OF CLOSED PNEUMOTHORAX AND PHRENICOTOMY ON THE CARDIORESPIRATORY FUNCTION

WILLIAM DEW. ANDRUS, M.D.
AND
J. D. WILSON, M.D.
Ranschoff Fellow in Surgery
CINCINNATI

A considerable amount of work has been done on the physiology of various phases of respiration, and a great many interesting data have been collected concerning the circulation through the lungs in different stages of their expansion or collapse. Such data are valuable, but since in normal respiration the degree of distention or collapse of the lungs is constantly changing, the results of such experiments can only by inference be applied to the complete respiratory cycle.

However, from a therapeutic point of view, we are more concerned with the sum of the reactions of the cardiorespiratory mechanism as a whole throughout its complete cycles and in response to various strains put on it through pathologic changes or in the course of therapeutic procedures.

STUDIES ON THE CARDIORESPIRATORY MECHANISM

Consequently, it has seemed to us worth while to study some of the effects on the cardiorespiratory mechanism as a whole of certain conditions associated with pulmonary compression, and to try to discover something of the mechanisms whereby the body compensates for these effects. While primarily interested in the amount of blood flowing through the lungs per minute, we have included the study of certain other phases as well.

Dogs which had been completely anesthetized with rectal ether after a preliminary hypnotic dose of barbital (administered intraperitoneally) were used for these experiments. An animal was tracheotomized and connected with a spirometer filled with oxygen and containing soda lime to prevent increase of the carbon dioxide as the gas was rebreathed. The spirometer was so calibrated that it could be read accurately to within 5 cc. Experimental data obtained included pulse rate, respiratory rate,[1] the volume of the tidal air, oxygen consumption per minute, the oxygen content of the arterial and mixed venous blood, and in some instances the right and left intrapleural pressures. The oxygen consumption per minute was taken as the average reduction per minute in the volume of gas in the spirometer over a period of rebreathing of five minutes or more. Arterial blood was obtained by puncture of the femoral artery

1. The tidal air volume was taken to represent the depth of respiration.

and mixed venous blood, by direct puncture of the right side of the heart through the chest wall. The needle was introduced in the fourth right interspace close to the sternum to avoid puncture of the right pleura. Samples of blood were analyzed for their oxygen content by the technic of Van Slyke. The respiratory volume per minute was calculated from the tidal air volume and the respiratory rate, and the amount of blood flowing through the lungs per minute was obtained by dividing the oxygen consumption per minute by the difference

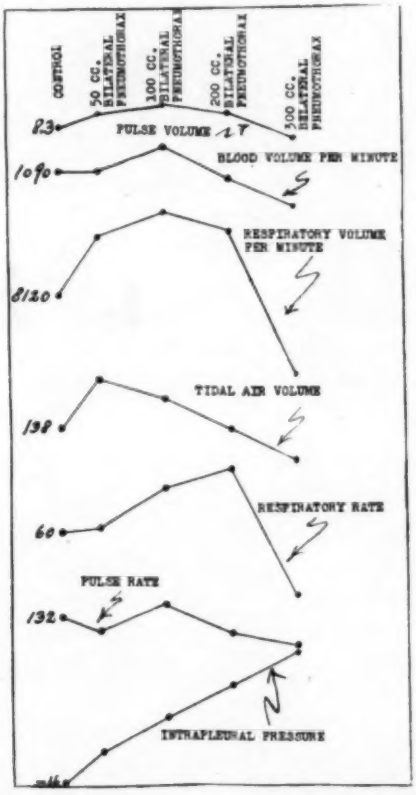

Chart 1.—Effect of increasing bilateral pneumothorax.

between the arterial and the venous oxygen contents. The pulse volume, of course, represents the blood flow per minute divided by the pulse rate. Practically no difference was noted between the effects of unilateral and bilateral pneumothorax of the same total amount.

The accompanying charts show typical experimental results. Chart 1 shows the effect of increasing bilateral pneumothorax in an animal weighing 10 Kg. Following the introduction of 50 cc. of air into each pleural cavity, the mean intrapleural negative pressure was decreased by 1 mm. of mercury. Coincident with this the tidal air volume was increased from 138 to 190 cc. (37.8 per cent) and the respiratory

volume, from 8,120 to 11,800 cc. per minute, or an increase of 45.3 per cent, largely due to deeper respiration. The amount of blood flowing through the lungs per minute was practically unchanged.

Bilateral pneumothorax of 100 cc. (200 cc. total) decreased the negative intrapleural pressure by one-half its normal value. The pulse rate was increased to 10 per cent above its initial rate, and the respiratory rate rose to 33 per cent above that at the beginning of the experiment. The tidal air volume began to fall, however, now being only 21 per cent above the first value, but due to the increased respiratory rate the total air breathed per minute was about 65 per cent above the initial amount, an increase of 5,260 cc.

The total amount of blood circulating through the lungs per minute now reached its maximum at 27 per cent above the resting value.

From this point onward, further increase in the pneumothoraces was followed by changes which may be interpreted as signs of beginning decompensation. Thus, bilateral pneumothoraces of 200 cc. (a total of 400 cc) reduced the mean intrapleural negative pressure still further to —1 mm. of mercury and caused a slowing of the pulse to 10 per cent below the rate at the outset. The respirations were increased to 90 per minute (+ 50 per cent) but were definitely labored, and even with the added effort they accomplished the inhalation of only the same amount inspired with the animal at rest before the beginning of the experiment. The respiratory volume per minute fell somewhat (10 per cent) from its peak, but due to the rapid respiratory rate it still remained 54 per cent above its initial value. This amount of pulmonary compression seemed definitely to interfere with the circulation through the lungs, for this was decreased by 31 per cent +, being now slightly below the resting value.

Bilateral pneumothoraces of 300 cc. each (600 cc. total) caused dangerous symptoms. The mean intrapleural pressure became practically 0, and the pulse rate had fallen to 25.3 per cent below the rate at the outset. Respirations became more labored and considerably slower (32 per minute, a decrease of 47 per cent), and the amount of air taken in with each inspiration fell to 25 per cent below the quantity at the beginning of the experiment (63 per cent below the peak). The respiratory volume per minute fell off sharply to about 60 per cent below its initial value (124 per cent below its peak). The circulation of blood through the lungs was also considerably interfered with and was reduced in amount to 26.5 per cent below its resting value (or 53.5 per cent below the maximum). The pulse volume was also decreased to 7 per cent below the initial value or 24 per cent below the maximum.

Thus, with an intact cardiorespiratory mechanism the body responds to the presence of closed pneumothorax by an increase in the pulse rate and pulse volume—after a slight initial slowing of the rate—

by an increase in respiratory rate, tidal air volume, and minute respiratory volume, and by increasing the amount of blood circulating through the lungs per minute. This compensation continues as the pneumothorax increases up to a certain point, which varies somewhat with the animal, but is followed by beginning failure of the cardiorespiratory mechanism as evidenced by sharp falls in all these factors.

The study was continued to include the effects of interference with certain other parts of the cardiorespiratory mechanism. The first of these studied was the effect of unilateral and bilateral paralysis of the diaphragm. Chart 2 shows a summary of these effects.

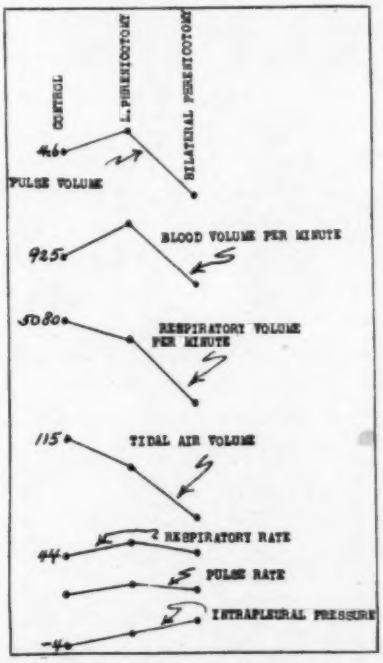

Chart 2.—Effect of phrenicotomy.

Unilateral phrenicotomy has been estimated to reduce the lung volume from one sixth to one third of its original value. Reference to the curves in chart 2 shows that in dogs paralysis of one half of the diaphragm produces effects quite comparable to those produced by a moderate pneumothorax. The mean negative intrapleural pressure is decreased somewhat, the pulse and respiratory rates are increased by about 10 per cent and the blood volume per minute is greater by 25 per cent than the resting amount. Because of the interference with the efficiency of inspiration, however, the tidal air volume and respiratory volume per minute are decreased by about 20 or 13 per cent, respectively.

So far, then, compensation has taken place, and indeed the pulmonary circulation seems definitely improved, as evidenced by the 25 per cent

increase in the blood flow per minute. Bilateral phrenicotomy, as would be expected, produces detrimental effects tending toward decompensation, and in this animal reduced the tidal air volume by 60 per cent, the respiratory volume per minute by 62 per cent and the quantity of blood flowing through the lungs per minute by 21 per cent, or to a point 45 per cent below that of unilateral phrenicotomy.

The reactions of an animal with unilateral diaphragmatic paralysis to pneumothorax are also of interest (chart 3). Whereas in the intact animal a pneumothorax of about 200 cc. produced an increase of the pulse rate, tidal air volume, respiratory volume per minute and the blood

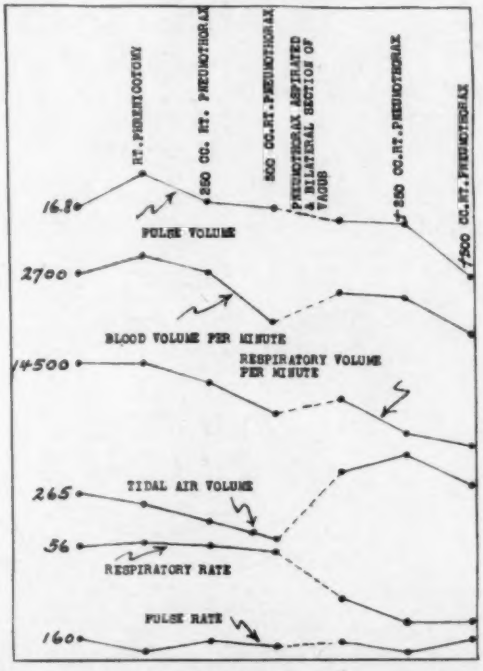

Chart 3.—Reactions of an animal with unilateral diaphragmatic paralysis to pneumothorax before and after bilateral section of the vagus.

flow per minute through the lungs, a similar pneumothorax when preceded by unilateral phrenicotomy causes a fall in all but the pulse rate, amounting in some instances to as much as 20 per cent of their previous values. Doubling the size of the pneumothorax produces grave symptoms of decompensation, as evidenced by reduction of the tidal air by 34 per cent, of the respiratory volume per minute by 39 per cent and of the blood flow per minute through the lungs by 38 per cent.

It is thus evident that the interference of such a factor with the depth of inspiration reduces the ability of the animal to compensate for an increased respiratory load.

The possible rôle of the vagus fibers to the lungs in the initiation of these compensatory changes is uncertain, but the reactions of an animal with bilateral vagotomy to pneumothorax are also interesting (chart 4).

Sectioning of the vagus nerves on both sides caused a slight increase in the pulse rate and slowed the respirations to one half of the previous rate. Coincident with this the depth of inspiration, as indicated by the tidal air volume, rose 150 per cent, and the respiratory volume

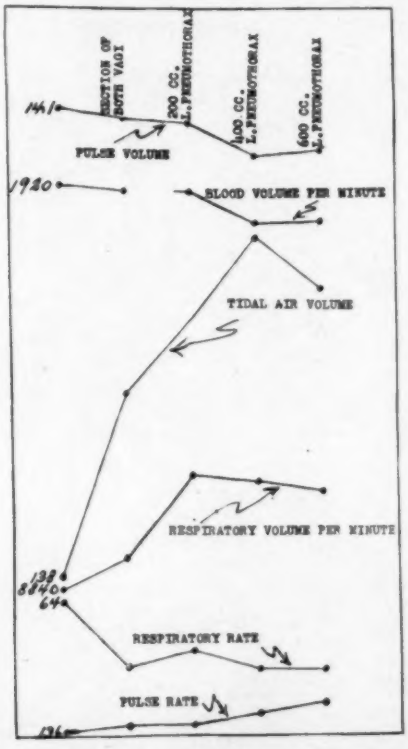

Chart 4.—Effect of unilateral pneumothorax after section of both vagi.

per minute was increased by 25 per cent. A slight decrease was noted in the blood flow per minute through the lungs (4 per cent) and in the pulse volume (9 per cent). A pneumothorax of 200 cc. here produced mixed effects. The respirations were slightly increased; the tidal air volume rose still higher, to 209 per cent above the amount before vagotomy was performed. As a result of this, the respiratory volume per minute was increased to 90 per cent above the initial amount. The quantity of blood circulating through the lungs per minute was slightly decreased, as contrasted with the 27 per cent increase in this factor produced by pneumothorax of equal size in the intact animal.

Doubling the size of the pneumothorax brought on signs of beginning decompensation and, except for an additional rise in the tidal air volume to + 270 per cent and a 12 per cent increase in the pulse rate, caused a sharp fall in all other factors measured. The amount of blood flowing through the lungs per minute was particularly affected, falling to almost 30 per cent below its initial value.

SUMMARY

1. A dog with an intact cardiorespiratory mechanism responds to a closed pneumothorax of moderate size by a slight increase in the pulse rate (10 per cent), a moderate increase in the respiratory rate (33 per cent) and tidal air volume (20 per cent) and a considerable increase in the respiratory volume per minute (65 per cent). In addition, the amount of blood circulating through the lungs per minute is increased by about 25 per cent and the pulse volume by about 15 per cent. Pneumothorax of a larger size causes symptoms of beginning decompensation, as evidenced by a fall in all these factors.

2. Unilateral phrenicotomy produces results similar to those produced by moderate pneumothorax, i. e., an increase of about 10 per cent in the pulse and respiratory rates, a moderate increase (about 25 per cent) in the amount of blood flowing through the lungs per minute, and an increase of about 15 per cent in the pulse volume. The tidal air volume and respiratory volume per minute are decreased by about 20 and 15 per cent, respectively, following hemiparalysis of the diaphragm.

3. Bilateral phrenicotomy produces symptoms of beginning respiratory decompensation in the dog.

4. A dog with unilateral phrenicotomy has a definitely decreased tolerance to further pulmonary compression, as evidenced by the fact that symptoms of beginning cardiorespiratory decompensation are produced by pneumothorax of a smaller size than is the case in an animal without hemiparalysis of the diaphragm.

5. Bilateral vagotomy causes a marked slowing of the respiratory rate (50 per cent) and an increase in the tidal air volume of 150 per cent and in the minute respiratory volume of 25 per cent. There is a slight decrease in the amount of blood flowing through the lungs per minute (5 per cent) and in the pulse volume (9 per cent).

6. Tolerance to pulmonary compression is also decreased following section of both vagus nerves.

ABSTRACT OF DISCUSSION

DR. E. A. GRAHAM, St. Louis: I should like to ask Dr. Andrus a question. I heard him say nothing about the amplitude of respiration.

DR. W. DEW. ANDRUS: Tidal air volume.

DR. GRAHAM: That answers it.

FUNCTIONAL ASPECTS OF BRONCHIAL MUSCLE AND ELASTIC TISSUE *

CHARLES C. MACKLIN, M.D., PH.D., F.R.S.C.
LONDON, CANADA

Few medical practitioners will be found who do not know that the bronchial tree contains smooth muscle, but probably not many realize that this muscle forms a motor organ extending uninterruptedly from the larynx to the outermost terminations of the air-carrying tubes, and infiltrating the entire lung substance. Indeed, on account of the thickness and uniformity of its distribution, one recent worker, Baltisberger,[1] has averred that hardly a cubic millimeter of lung substance in the human being could be found which would not contain smooth muscle. There are reasons why the presence of this abundance of pulmonary muscle has not been observed earlier. One undoubtedly is the fact that in ordinary microscopic sections of the lung so much space is occupied by air that the tissues are spread apart, and the muscle elements, thus dispersed, do not bulk so large as they would if all the air could be eliminated and the muscle specifically stained. In such a case one would be struck at once with the relatively large amount of muscle present. Again, the muscle in the lung tissue occurs in delicate wisps, sometimes only a cell or two in thickness, and, since distinctive stains for muscle are seldom used, it does not contrast sufficiently with adjacent tissues to be appreciated.

ANATOMY OF THE BRONCHIAL MUSCULATURE

This muscle is not distributed in any haphazard fashion in the lung; on the contrary, it is built up in a characteristic and systematic manner. Most of it is in the walls of the airway, and is known as the bronchial musculature. This is by far the more important division. Some of the muscle, however, is scattered as slender strands and filaments in

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* From the Department of Anatomy of the Faculty of Medicine of the University of Western Ontario.

* Credit for assistance in the preparation of this paper is gratefully acknowledged to the Marine Biological Laboratory, Woods Hole, Mass., where a work room and library facilities were placed at my disposal.

* This article is mainly a synopsis of a monograph entitled "The Musculature of the Bronchi and Lungs" which appeared in *Physiological Reviews*, vol. 9, no. 1, January, 1929. This contains a full bibliography. For a more thorough treatment of the different subjects, the original should be consulted.

1. Baltisberger, W.: Ueber die glatte Muskulatur der menschlichen Lunge, Ztschr. f. Anat. u. Entwickl. **61**:249, 1921.

the interstitial tissue of the lung, and has, accordingly, been termed the interstitial musculature.

The bronchial musculature is found throughout the airway, and this means throughout the lung tissue. In the trachea it exists in the posterior, flaccid, membrane as thin transverse strands which tie together the ends of the cartilage crescents. Some fibers, particularly in the region of the carina, course obliquely, or longitudinally.

In the main bronchi there is much the same arrangement, the fasciculi of muscle, at first, bridging the interval between the cartilage ends; but soon, as the cartilages come to be distributed around the entire wall, the muscle also becomes a complete layer, lying as a delicate tubular network between the cartilages and the mucosa. The predominant course of the strands in the larger tubes is circular, and the elongated, transverse meshes vary in size and shape depending on the state of elongation or contraction of the tube. This netlike muscle tube is an integral part of the wall; there is no interruption in it, and it branches and rebranches with the air tubes, the caliber progressively becoming smaller and smaller. The area of the cross-section of the branches, however, always exceeds that of the parent trunk. The muscle, too, becomes actually more delicate as the tubes become smaller, but, when considered in relation to the bulk of the other constituents in the wall the muscle is more prominent. This is particularly true of the fine terminal bronchioles which mark the end of the purely conducting part of the airway, and lead over into the combined conducting and respiratory part. In the terminal bronchioles the muscle is relatively heavy, and is capable, apparently, of obliterating the lumen of the tube, on contraction (figs. 1 and 2).

The anatomy of the conducting part of the airway is familiar to every surgeon, and need not be discussed here. But when the terminals of the airway are considered—the conducting and respiratory portion—it is found that the anatomy is not usually so well known and, on this account, a short description will be given of this, more recently studied, division, as a preliminary to the consideration of the muscle in its walls.

The fine terminal bronchioles of the air system, corresponding to the finer arterioles of the blood system, are relatively narrow; indeed they are said to be the narrowest part of the airway. They branch into the respiratory bronchioles, so called because their walls are broken by openings leading into air-holding chambers, some of which are clothed by cuboidal epithelium; others are covered with such thin-walled epithelium as to make them capable of allowing gaseous interchange between the air and blood. As these respiratory bronchioles are traced outward, the openings become more numerous and larger. They branch into wider tubes, which are of characteristic appearance, and are called

alveolar ducts. These ducts are important air-carrying tubes. Their walls, if they can be called walls, are mere, large-meshed sieves, the rounded openings sometimes leading into branches like themselves, but more frequently into loculated alveolar sacs, which end blindly. These alveolar sacs, or air-sacs as they are often called, are often partially divided by low, crescentic partitions, into two or more chambers, which are known as alveoli. Thus the alveoli are mainly subdivisions of the

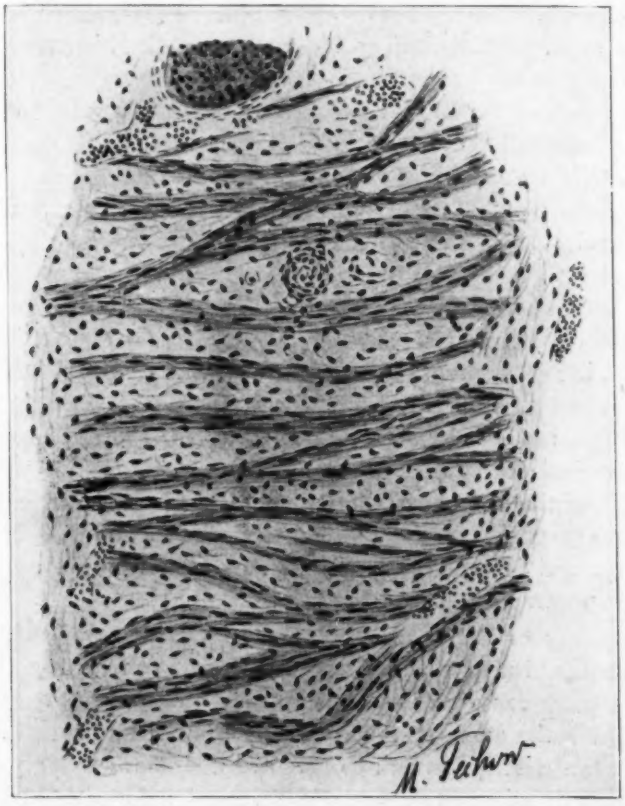

Fig. 1.—(From Eduard Müller, Zur Anatomie der Bronchialmuskulatur, Sitzungsb. d. Gesellsch. z. Beförderung d. ges. Naturwiss. z. Marburg, May, 1913, abb. 2.) Musculature in a bronchus of 0.8 mm. diameter from a new-born child.

alveolar sacs. Some, however, open directly from the alveolar ducts or respiratory bronchioli; in this case a unilocular alveolar sac and an alveolus would mean the same thing.

Thus the pulmonary lobule, or acinus, which is all that branched complex of air tubes, air chambers and their adnexa, the stem of which is the respiratory bronchiole, is complicated. It is only recently that its labyrinthine character has been visualized. The accompanying figure

of Willson [2] (fig. 3) will assist in giving some idea of this structure, or, more correctly, a small portion of it. A terminal bronchiole [3] (*1*) is shown dividing into two respiratory bronchioles, each of which (*2*) again divides into two alveolar ducts. Only one of these (*3*) was followed by Willson,[4] in his study, and this divided twice in rapid succession (*4, 5*). Only one of the latter branches [5] (*6*) was traced to its ultimate terminals. These ramifications (*7* to *26*) were all pro-

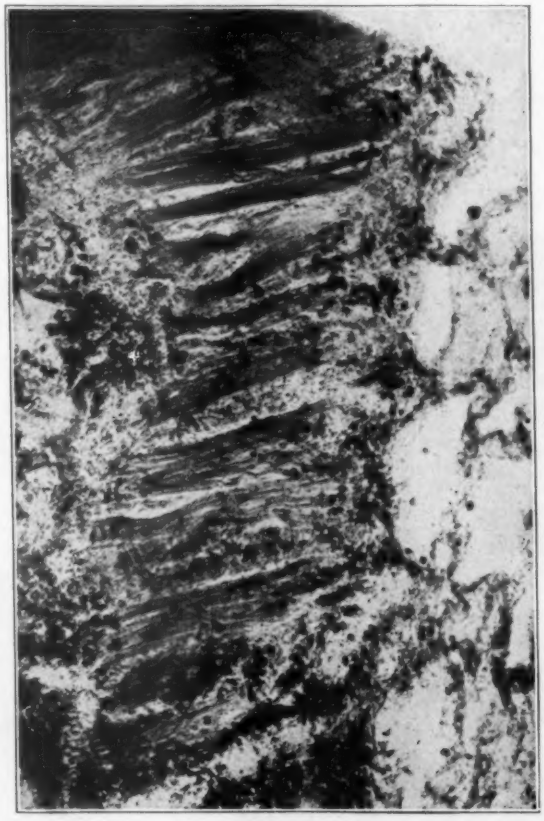

Fig. 2.—(From William Snow Miller, Am. Rev. Tuberc. **5**:693 (Nov.) 1921, fig. 2.) Muscle bands from bronchiolus from the lung of man.

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2. Willson, H. G.: The Terminals of the Human Bronchiole, Am. J. Anat. **30**:267 (May 15) 1922; The Emphysematous Lung, Univ. Toronto Med. Bull. **8**:9 (Dec.) 1927.

3. Macklin, C. C.: The Musculature of the Bronchi and Lungs, Physiol. Rev. **9**:1 (Jan.) 1929.

4. Willson (footnote 2, first reference).

5. Kölliker, A.: Mikroskopische Anatomie der Gewebelehre des Menschen, 1852.

jected on a sheet of paper. On this branch and its ramifications alone one can count some seventy-one alveolar sacs of various sizes, to say nothing of the many small alveoli. Thus the number of respiratory chambers in a single pulmonary lobule must be enormous. Willson noted much variation in the size of the alveoli, and of the air sacs, and found many respiratory chambers which might with equal propriety be called either large alveoli or small air sacs.

In the lobule the essential happenings of external respiration—the gaseous interchanges between the air and the blood—go on. It must, therefore, be capable of being ventilated—of expanding and contracting.

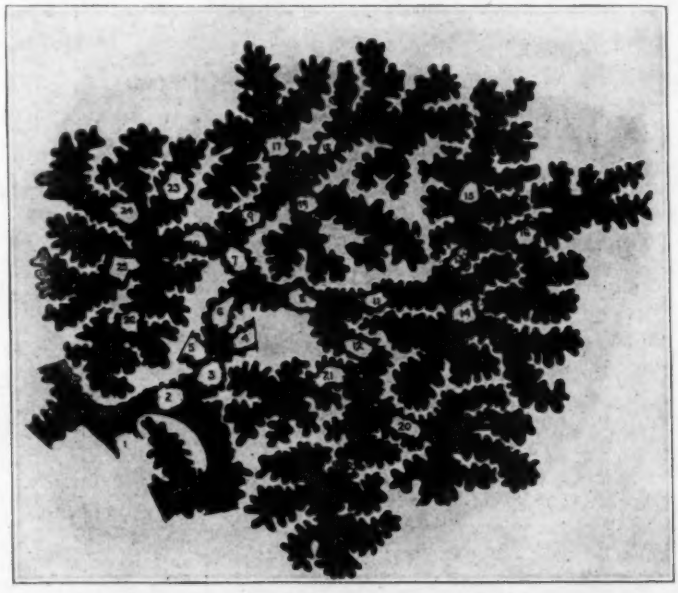

Fig. 3.—(From Willson, Herbert G., The Emphysematous Lung, Univ. Toronto Med. Bull. **8**:11 (Dec.) 1927.) Diagram of some of the terminal ramifications of a nonrespiratory bronchiole of the lung of a child, projected on a single plane. All these branchings occur in a piece of lung about the size of a pinhead.

Indeed Keith [6] has termed it, rather appropriately, the "bellows part" of the lung. To understand its action is to understand the mechanical action of the lung; and the muscle is an important, indeed an indispensable, element in it. I shall now return to a consideration of this muscle.

The network, mainly of circular fibers, passes directly on from the terminal bronchioles into the pair of respiratory bronchioles, and thence, without interruption, into the ultimate ramifications of the alveolar ducts, and some of its fibers even dip into the lining of the alveolar sacs.

6. Keith, A. The Mechanism of Respiration in Man, in Hill, L.: Further Advances in Physiology, London, Arnold, 1909.

In the respiratory bronchiole the muscle strands run obliquely, or, as Miller [7] has aptly expressed it, in "geodesic lines." When openings occur in the walls the strands encircle these, but the muscle here, and everywhere, is to be regarded as part of the wall of the tube rather than as belonging to the outpouching. If such a tube is split open and laid flat, with the muscle appropriately stained, it would look as shown in figure 4, from Baltisberger.[1] The openings outlined with black lines lead into alveoli. Figure 5 shows the muscle as seen in

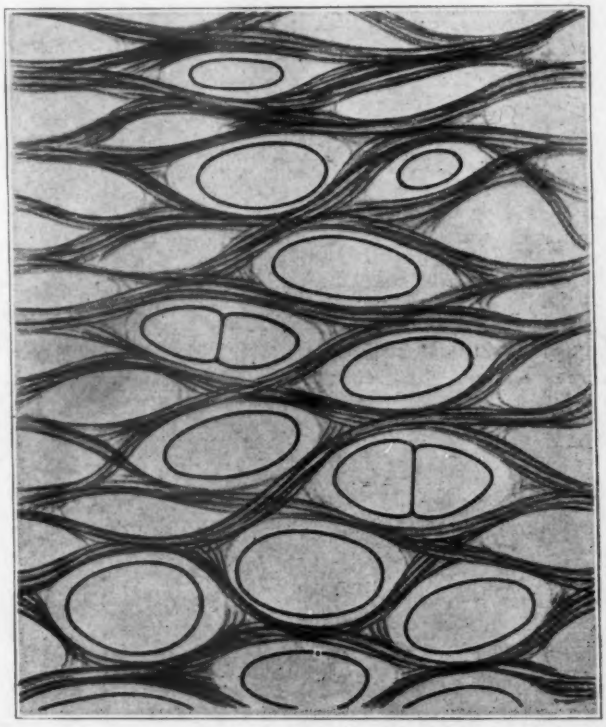

Fig. 4.—(From Wilhelm Baltisberger, Ztschr. f. Anat. u. Entwickl. **61**:259, 1921, abb. 4.) Diagram of the wall of a respiratory bronchiole, in man, split lengthwise and laid flat. The longer, vertical axis is the axis of the tube. The cut was made along the line of contact of the pulmonary artery, where there are no alveolar outpouchings. In the central part of the field, opposite the artery, the alveoli are numerous, particularly in the lower part of the field, which is the most peripheral region.

longitudinal sections of this tube. It is cut transversely and is marked m_1 to m_4; "*a*" is an alveolus lined with cuboidal epithelium; s_1 to s_3 indicate the walls between the alveoli.

7. Miller, W. S.: The Musculature of the Finer Divisions of the Bronchial Tree and Its Relation to Certain Pathologic Conditions, Am. Rev. Tuberc. **5**:689 (Nov.) 1921.

In the alveolar ducts, the meshes of the net become larger and larger, since so much of the essential wall is occupied by the openings into the offshoots already described. The muscle net of the wall of an alveolar duct, if split open and laid flat, would appear loose, with

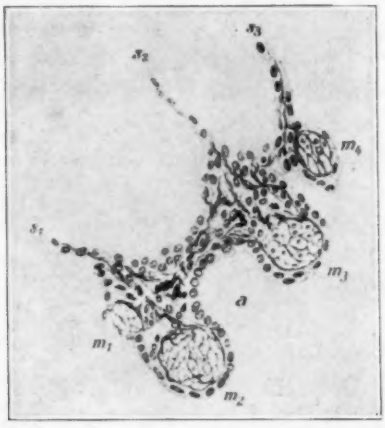

Fig. 5.—(From Baltisberger, abb. 2, p. 256.) Section from the wall of a respiratory bronchiole, in man, showing four muscle bundles, m_1, m_2, m_3, and m_4, cut transversely or obliquely; a is an alveolus, lined with cuboidal epithelium.

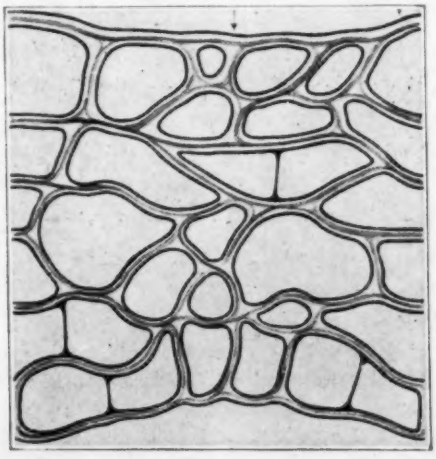

Fig. 6.—(From Baltisberger, abb. 9, p. 265.) Diagram of the wall of an alveolar duct, in man, which is represented as split lengthwise and laid flat. The vertical axis of the figure is the axis of the duct. The air sacs are outlined in black, and the muscle network is represented in gray.

delicate strands, as shown in figure 6, from Baltisberger. Strands from the muscle net of the alveolar ducts are often continued into the alveolar sacs. The larger sacs have a similar wall, but it is even more

delicate, and the muscle is lacking in many of the edges of partitions separating alveoli. In such cases the thin margin of the partition is made up only of delicate strands of white fibrous and yellow elastic tissue.

Reproductions of figures from Baltisberger's fine work are here given to make the meaning clearer, and to enable one to visualize the complicated structure of the terminal air ducts and chambers. In figure 7 is

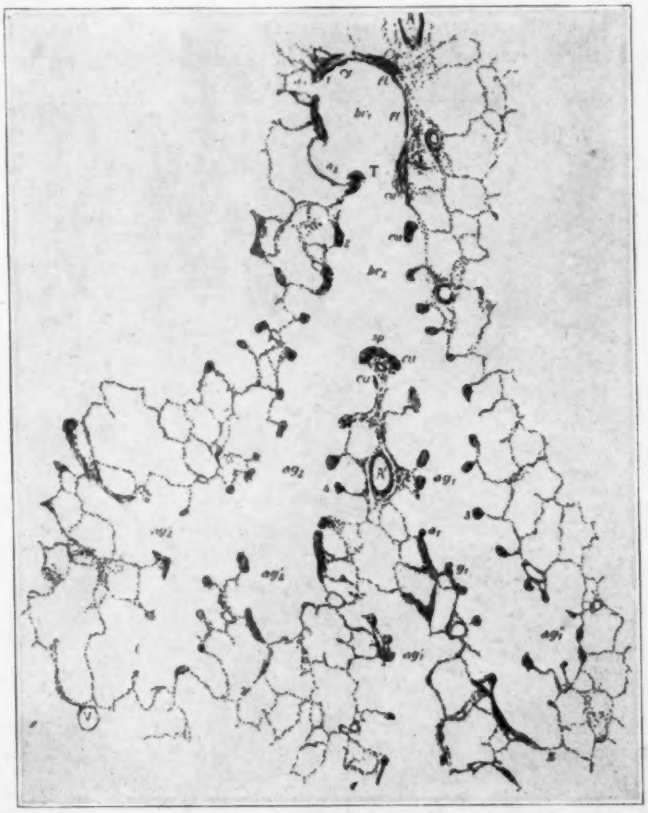

Fig. 7.—(From Baltisberger, abb. 3, p. 257.) Drawing of the branching of a respiratory bronchiole into two alveolar ducts in lung of man. The sections of the muscle bundles are represented in the dark nodules, apparently projecting into the ducts and attached by slender stalks. The latter really represent the interalveolar partitions. The muscle rings have been cut in many different directions.

shown a respiratory bronchiole br_1 cut directly across, in the upper, or apical, part of the picture. The openings in the wall are seen, leading into alveoli a_1 and a_2. The muscle is cut almost directly longitudinally. The tube leads, at "*T*," into a branch like itself, br_2, which branches into two alveolar ducts, ag_1 and ag_2. All along the walls of these tubes

the cut muscle appears as small dark nodular structures of various sizes and shapes. Each nodule is connected outwardly with a thin partition, separating adjacent air chambers. For the most part, the muscle rings are cut directly across, or at a sharp angle, but some are cut tangentially, and appear as more elongated structures, in the figure. This is a favorable section, since the alveolar ducts are cut longitudinally. It is not always possible to secure them so cut. The nature of the alveolar sacs is well seen. One readily grasps how contraction of this tubular net would diminish the space within, and tend to force the air either laterally, into the air chambers, or forward, along the tube,

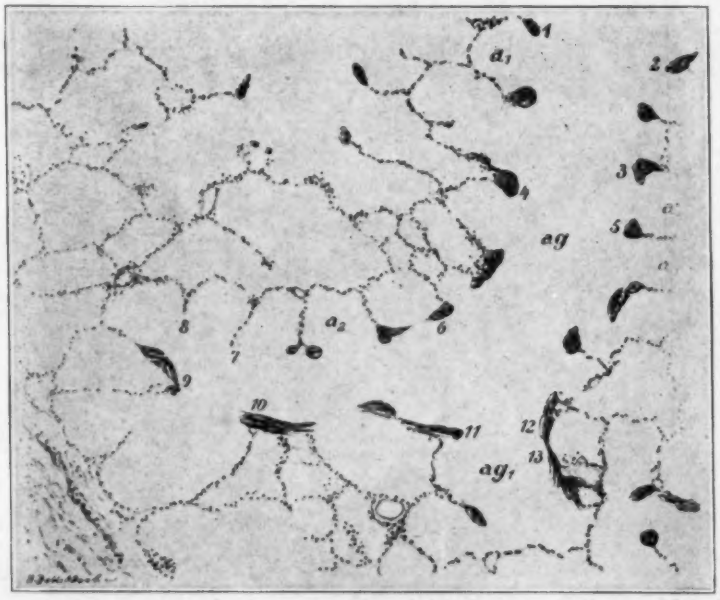

Fig. 8.—(From Baltisberger, abb. 5, p. 262.) Drawing from a section cut longitudinally along an alveolar duct in a human being. The muscle bundles, shown as a double row of dark nodules, which line the lumen of the duct, have been cut in different directions. The muscle bundles have numbers, and the air sacs are marked a_1, a_2, etc.; *ag* is the lumen of the alveolar duct.

toward the larger bronchi. The latter movement, of course, occurs in normal expiration, as this is the direction of least resistance.

Figure 8 shows, again, a longitudinal section along an alveolar duct, *ag,* at a somewhat higher magnification. The muscle lines the lumen of the tube, and is seen in the darker, stouter, structures. As before, the rings have been cut at various angles. If, instead of a thin section, one were looking into a slice of tissue which would show the far side of the tube, it would be seen that the muscle formed a network as described, and as shown spread out flat in figure 6.

In figure 9 is seen another thin section through an alveolar duct, showing the muscle grouped about the central lumen, marked *ag*. The muscle nodules are numbered 1 to 6, and each is but part of a circle. The elastic tissue infiltrating the muscle is not seen in these figures. In figure 10 is shown a tangential section along the wall of an alveolar duct which shows how these sphincteric muscle structures are woven together to form the wall. Figure 11 shows a section across an alveolar duct, *ag*, in which a complete circle of muscle is shown. Not many

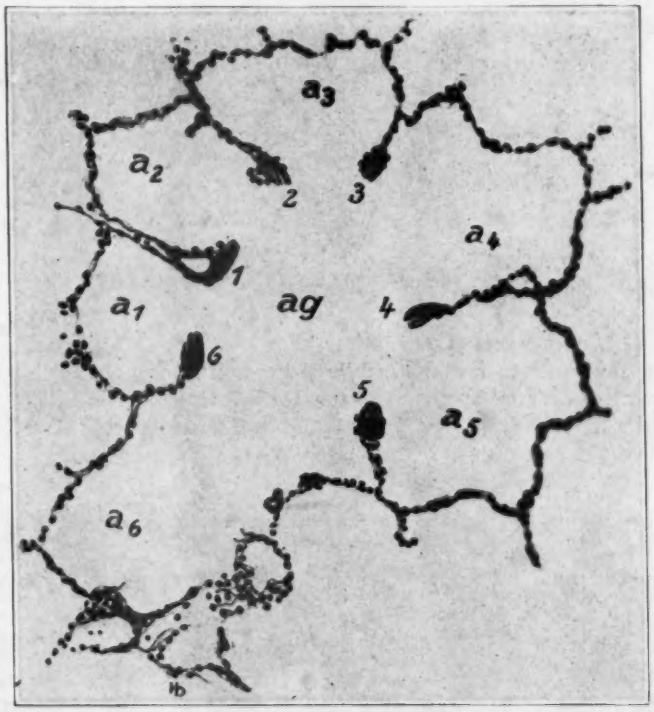

Fig. 9.—(From Baltisberger, abb. 6, p. 263.) Drawing showing a cross-section through an alveolar duct *ag* in a human being. The muscle bundles, cut for the most part transversely, bear numbers, and the air chambers bear the general designation *a*, and they show a typical rosette form.

such are seen in a field. Although no openings into outlying respiratory chambers appear in this section, they would come into view in adjacent sections, if these could be seen. Figure 12 is a photomicrograph of one of my own preparations from the lung of a cat, showing a somewhat similar muscle ring.

Nowhere is muscle found in the walls of the alveoli—only in the mouths of these—and not always there. It is always to be regarded as belonging to the tube or sac into which the alveolus opens, and never as part of the alveolar wall.

In the alveolar ducts and larger alveolar sacs the lining presents an appearance reminiscent of the lungs of the lower vertebrates, such as the frog. Indeed, it has long been known that the unit of the mammalian lung, including that of man, is built up like that of these lower animals; and Kölliker [5] and others, many years ago, called attention to

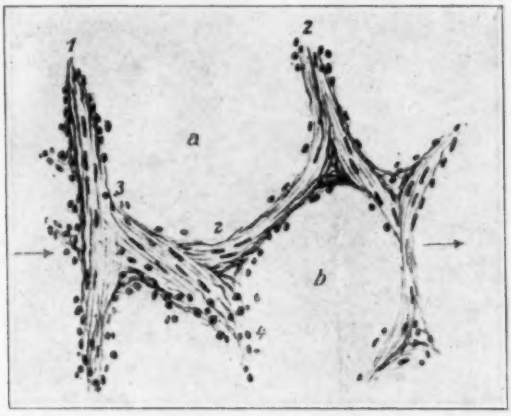

Fig. 10.—(From Baltisberger, abb. 8, p. 264.) Tangential section along the edge of an alveolar duct in a human being, showing the way in which the muscle bundles interlace with one another. The arrow indicates the long axis of the duct. The numbers indicate muscle bundles running in different directions; *a* and *b* are openings into air chambers.

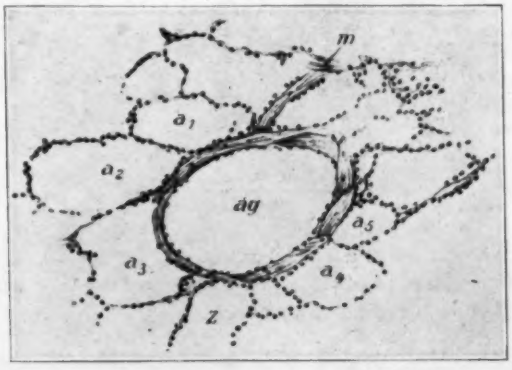

Fig. 11.—(From Baltisberger, abb. 7, p. 263.) Oblique section through an alveolar duct in a human being, cut through the muscle in such a way that a complete ring appears in the section. The muscle fibers in this ring, however, appear interwoven. *ag* marks the lumen of the duct.

this resemblance. Because of this similarity I am here showing the interior of a loculus of the lung of the turtle (fig. 13). In structure it is essentially like the larger alveolar ducts of the lung in man, but is built with chambers of much greater size and much heavier parts. The lining

of the loculus will be seen in the surface network in which, as in the mammalian lung, the muscle fasciculi are by far the most bulky constituent. A cross-section of one of these lining strands, stained to show the muscle, is presented in figure 14. The muscle is here much more dense than in the mammalian lung, as a comparison with figures 10, 11 and 12 will show, and the interalveolar partition joining it is considerably heavier, and has a capillary field on either side, but the general arrangement is the same.

Thus it is seen that whatever "wall" there is in the air tubes of the pulmonary acinus is made up of this muscle net with its infiltration

Fig. 12.—Photomicrograph from moderately inflated cat lung. The muscle ring does not lie quite in the optical plane. Compare with figure 17, showing elastic tissue in a similar region. Appearances of this kind are found everywhere in thick sections of this kind. (Author's preparation.)

of elastic tissue; for the covering of epithelium and tunica propria which this network bears is exceedingly thin. The wall is thus a tubular, branched, contractile, myo-elastic net. Of what use is it? Why is it there? An answer to this question will not be attempted until another important and closely related structure, the elastic-tissue structure of the bronchial tree, is described. This is so intimately interwoven with the muscle as almost to compel the term myo-elastic complex rather than either muscle or elastic tissue alone, for the two are functionally inseparable.

The Elastic Tree.—Like the arbor musculosa, the arbor elastica is found as a continuous system from the larynx to the alveoli, and, not stopping with the mouths of the final air chambers, as in the case of the muscle tree, it is continued on, as exceedingly delicate strands, into the alveolar walls.

In the larger tubes the elastic tissue is in several layers, which have been well described by James Miller.[8] An illustration from this author

Fig. 13.—Photomicrograph of the interior of the lung of a turtle, which had been stained and cleared. Note the lacework of muscle (interwoven with elastic tissue), presenting on the upper surface. The more or less complex and subdivided air chambers will be seen through the meshes. (Author's preparation.)

is reproduced in figure 15, and shows exceedingly well these different layers in the wall of a large bronchus. The most striking and con-

8. Miller, J.: The Arrangement of the Elastic Fibers in the Bronchi and Lung, J. Anat. **40**:162, 1906.

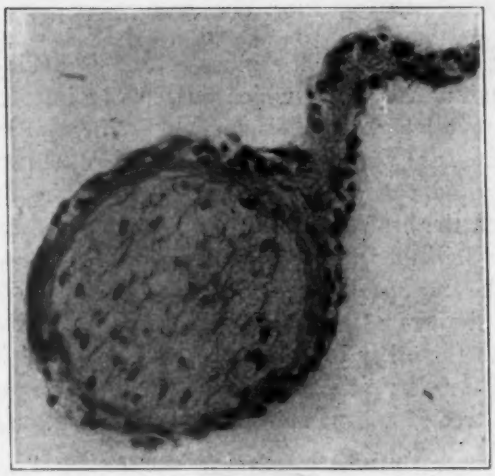

Fig. 14.—Photomicrograph of a section through the myo-elastic network lining such a loculus of turtle lung as that seen in figure 13. Note the dense muscle, and the apparent stalk, which is a partition between adjacent air chambers. Compare with figure 18, which shows the elastic tissue in a similar region.

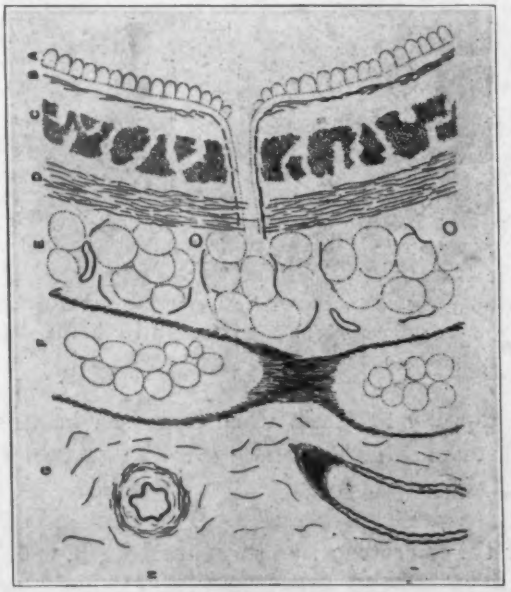

Fig. 15.—This is figure 1, from the article by James Miller in J. Anat. **40**:164, 1906. *A* indicates epithelium; *B*, sub-basement membrane layer; *C*, longitudinal layer; *D*, muscular layer; *E*, stratum of mucous glands containing a few irregular fibers and those in connection with vessels; *F*, layer enclosing cartilage nodules; *G*, fibrous tissue of wall containing some irregularly-running fibers, also vessels; *H*, bronchial artery, and *I*, pulmonary artery. The elastic membrane *C* and the layer of elastic fibers in the muscle *D* should be noted. See text for discussion.

spicuous layer is situated in the mucosa, and is made up of strands which run longitudinally, and which are closely interfelted. The cut ends of this stout layer, which is known as the elastic membrane of the bronchial tree, are well shown in figure 15, in the layer labelled "*c*." It is continuous, as a distinct membrane, though diminishing in thickness, throughout the bronchial tree to the finer tubes, and in the lobule it blends with the other layers to form the network which is interwoven with the muscle already described. This layer, of course, branches with the branching of the air tubes, and always keeps the same relation to the other layers of the wall. It is plainly seen in all bronchi stained for elastic tissue. This layer can be dissected out in the fresh bronchial tree of a large animal such as the pig, and then is found

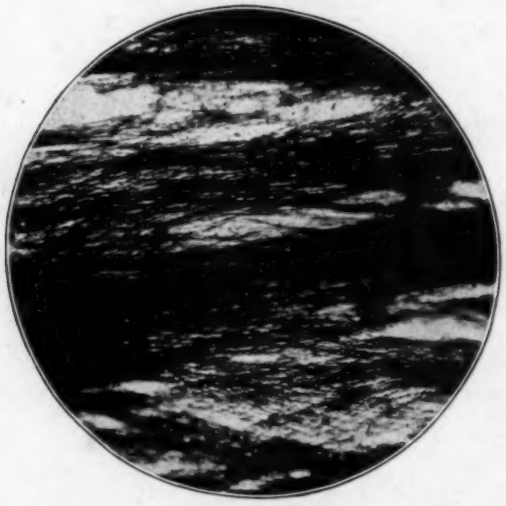

Fig. 16.—Spread preparation of elastic membrane from a large bronchus of the pig, stained with resorcin-fuchsin and teased, after having been cleared in oil of wintergreen. (Author's material.)

to possess the capacity to recoil, when stretched, in a marked degree. If stained with resorcin-fuchsin, and the fibers separated by teasing with needles in clearing fluid, as oil of wintergreen, after preliminary dehydration and treatment with benzene, a preparation is made which appears, under the microscope, as in figure 16. It will be noted both in this and in figure 15 that the ultimate elastic fibrils are fine, but of somewhat variable thickness, and that they branch characteristically; furthermore, they are grouped in fasciculi, which also branch. This provides for dilatation of the tube, in addition to lengthening.

Outside of this elastic membrane is a layer of elastic fibers which run mainly circularly (fig. 15, *d*), and which are interwoven with the muscle, as already described. In the trachea they are plainly seen in

the flaccid part of the wall. They run through and through the muscle. This layer continues on into the lobule, and blends with the elastic membrane as described. The conspicuous network which it forms in the muscle of the lobule is seen in figure 17, from a preparation of the lung of the cat similar to that shown in figure 12, but stained specifically for elastic fibers. These two figures should be compared for an understanding of the relation of the elastic fibers to those of the muscle. A cross-section of the elastic tissue and muscle in the turtle, showing the elastic tissue with ends cut across, which appear in the figure as black dots, or star-shaped structures is seen in figure 18. As already

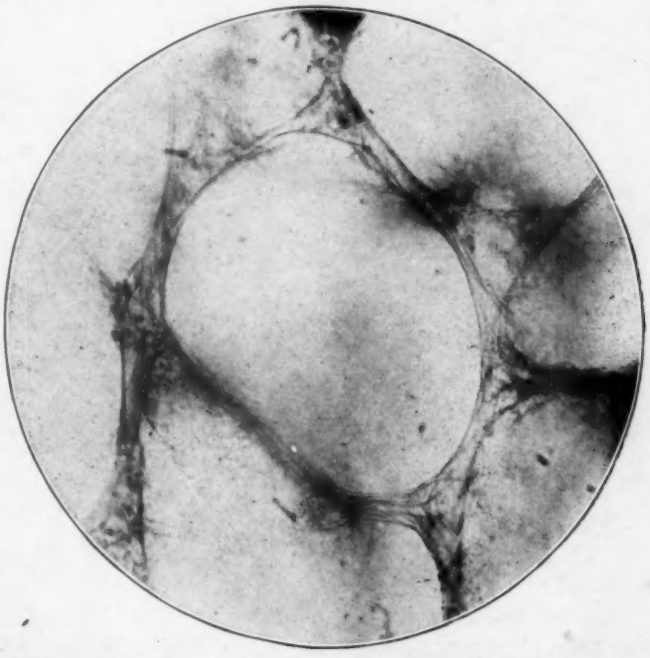

Fig. 17.—Photomicrograph of a preparation of cat's lung, showing a ring of elastic tissue leading into an air chamber. Stained with resorcin-fuchsin and cleared. Muscle does not show. Compare with figure 12, which is from a similar structure, but stained to bring out the muscle. (Author's material.)

stated, this structure in the turtle is relatively heavier than in the mammal, but the general relationship of muscle and elastic tissue is the same. The elastic tissue, here, is particularly dense in the peripheral region of the fasciculus, as shown.

Other layers of elastic tissue have been described, particularly in the larger tubes (fig. 15). Although many fibers run obliquely, the characteristic directions are longitudinal and transverse. They are obviously built to permit of changes in length and width in these tubes. Their function, in association with that of the muscle, will be considered in the next section.

Thus there is in the lung a great muscular organ, or, more accurately, a great elasticomuscular organ, the general form of which is a replica of the entire bronchial tree. If one were able to dissolve away all other tissues from the bronchial tree except this organ, the form of the tree would still be preserved accurately and completely. It is a mere platitude to say that this organ is found in all parts of the lung, for it, itself, composes an integral part of the lung tissue. Indeed, the term lung tissue means nothing more nor less than the interdigitated, complexly branched, lung lobules, or terminal branches and leaves (alveoli)

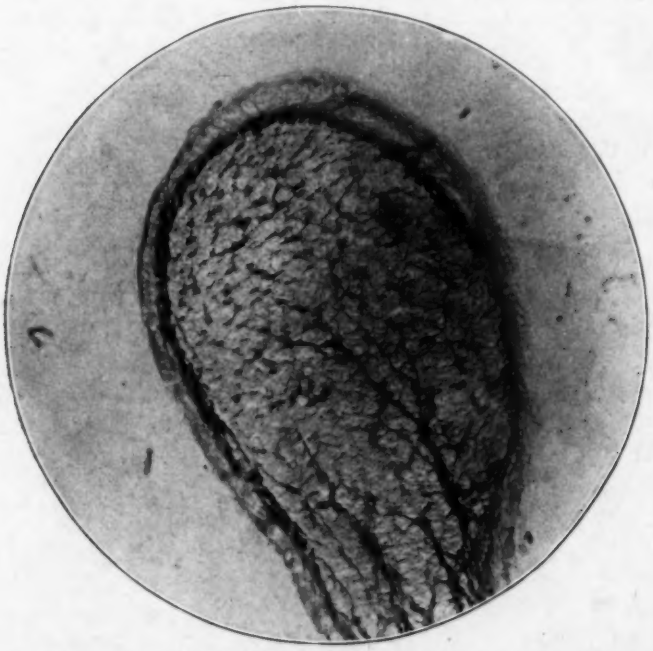

Fig. 18.—Somewhat oblique section through elastic net of turtle lung, stained to show elastic tissue, which appears as dark dots and stellate structures. There is a heavy band on the periphery. Compare with figure 14, which shows the muscle in a similar piece of material. (Author's specimen.)

of the bronchial tree. If one could disentangle these lobules, with their associated blood and lymph vessels, nerves and supporting tissues from one another, there would be no "lung substance" left, apart from them.

This organ forms an important part of the walls of the air conduits, through which air is constantly ebbing and flowing. Because it is this type of motion, there must be provision for enlargement and diminution of the lumen of these tubes, and this recoil and motor mechanism is the basis for this provision. All the space within the bronchial

tree save that within the alveoli is really the anatomic dead space, and that this is a variable space—not at all a fixed space as some believe—will be shown. All lungs are built on this fundamental plan, even down to the most simple, as that of the frog. This motor organ is found throughout all the lung-endowed group of animals; it is universal in its distribution and may well be regarded as indispensable to life.

FUNCTION OF THE BRONCHIAL MUSCLE

The function of the bronchial muscle and its associated elastic tissue is bound up with the movements which occur in the bronchial tree. Those in which muscle action may be involved are as follows: (1) changes in length; (2) changes in width, and (3) peristaltoid movements.

When one examines the roentgenographic, bronchoscopic and other evidence, it is found that there is, in inspiration, an elongation and a widening of the air tubes, and, in expiration, a shortening and narrowing of them. These movements occur, of course, only in active parts of the lung, that is, only in those parts of the lung into which air is entering, or from which air is leaving. It follows that, in ordinary quiet respiration, since some lung regions are quiescent, no movement of this kind will be found in the tubes supplying them, and, if the ebb and flow of air is slight in any region, there will be a corresponding slightness in the movement in that part: indeed, it may well be that changes in width, particularly, are at times absent. But the general principle remains that there can be no natural ventilation of any part of the lung without an elongation of the tubes supplying it. When the healthy lung is undergoing maximal ventilation, as in prolonged vigorous exercise, all the tubes, including the trachea and main bronchi, are stretched in inspiration, and are shortened in expiration. With the elongation there is widening, and with the shortening, narrowing. When one stops to think about the matter, it is apparent that the lung could not be inflated if the bronchial tubes were rigid—like gas pipes, as Reisseissen [9] more than a hundred years ago, and as Chevalier Jackson [10] recently, pointed out. Ventilation under such conditions would be limited to a thin layer of subpleural tissue. On the other hand, it is impossible to conceive of a lung, once inflated, as being deflated without a shortening of all of the tubes supplying the lung regions from which air is flowing out. With inflow of air, then, into any part of the lung, there is elongation and widening of the tubes carrying that air; and, with outflow of air from any part there is coincident

9. Reisseissen, F. D.: Ueber den Bau der Lungen, Berlin, 1822.

10. Jackson, C.: The Bronchial Tree—Its Study by Insufflation, Tr. Am. Laryngol. A., 1918, p. 319.

shortening and narrowing of the tubes. These movements are indissociable from respiration.

In inspiration there is a flow of air into the lung because the pressure in the outside atmosphere is greater than that in the lung tissue. This air pressure distends the distensible parts of the lung lobule, and the effect of the swelling of adjacent air chambers is to stretch the tubes on which they abut and to which they are attached. It also has the effect of dilating the air channels, which action, in the tubes of the lung lobule, is probably accomplished by the centrifugal pull on their walls arising from the distention of the outlying and attached air chambers.

Now, in the elongation and dilatation of inspiration it cannot be said that the muscle plays an active part; on the other hand, the most that could be expected of the muscle is that it should relax, during inspiration, in order to offer no obstruction to the inflow of air. The myo-elastic tube, as we have seen, is built to permit of being stretched, the meshes of the muscle opening out, and the longitudinal elastic tissue elongating. But in expiration it is another matter; the muscle is in a position to narrow and to shorten the tubes when it contracts. Its shortening action is slight, or perhaps almost nil, in the larger tubes; indeed, in the trachea, it can hardly exert any shortening influence except possibly slightly at the carina. But in the smaller tubes, where the strands run obliquely, contraction of the muscle must necessarily shorten them. An orderly, progressive contraction, beginning at the periphery of the air tube system and sweeping toward the trachea would diminish the volume of air in the bronchial tree, particularly in the peripheral part, or lung lobule. This movement must be sharply distinguished from a spasm of the muscle, particularly in the peripheral bronchioles, such as occurs in asthma, which has the effect of trapping air in the lobule and distending the alveoli, instead of evacuating the lung of tidal air. Such an orderly, expulsive, movement would act in conjunction with the elastic tissue. In inspiration the longitudinal fibers are put on the stretch by the lengthening of the tubes, and the circular and oblique fibers are similarly influenced by the dilatation of the tubes. In expiration, therefore, these stretched fibers recoil, and the tubes are shortened and narrowed. Indeed, most of the shortening action in the larger tubes is probably due to the recoil of the stretched elastic tissue. In the terminal chambers of the lobule, the alveolar sacs, the recoil of the elastic tissue and the contraction of the muscle have the effect of narrowing the mouths of the alveoli, changing the latter from the shape of a saucer to that of a cup. In this way the alveoli are ventilated with little or no stretching of their walls. Indeed, the mesh of the myo-elastic net is a ring, surrounding the opening into the air chamber, and this ring may be looked on as

a sphincter, although it never completely closes, but merely widens and narrows. This round-meshed fabric forms the tubular "lining" of the alveolar sacs and, even more typically, of the alveolar ducts. The dilatation and lengthening of this tubular network is accompanied by an opening up of the orifices into the air chambers, while, contrariwise, the shortening and narrowing of this net is associated with a narrowing of all of these openings.

Thus, in inspiration, the entire bronchial tree, even to its end twigs, lengthens and dilates. Its capacity is increased—in forcible breathing greatly increased. This movement has been graphically shown by different methods at this meeting by Francis, Heinbecker and Hudson, the last mentioned using motion pictures made by a most ingenious method. In this way the air has freedom of entry, and the alveoli have efficient ventilation. In expiration the tubes shorten and become narrowed; the "dead space" is diminished, and the used air driven out. The greatest amount of volume change is in the lobule—the true pulmonary bellows. The lumen of this is the most variable part of the dead space. In this process of expulsion the elastic tissue, of course, plays an important part, but it seems within the bounds of reason to assume that the bronchial musculature may also act. The muscle system would thus function as a deflation agent. If it does not do so then this elaborate motor system must be looked on as being of use only in emergencies, or as having some mysterious function that is not at all understood at the present time.

Peristaltoid Movement.—It has been known for some time that the bronchial tubes have a way of freeing themselves from harmful exudates, or injected foreign materials, other than by the act of coughing, or by the action of the cilia. This third device is a continuous wave motion, traveling from the periphery toward the center. It has been demonstrated by Reinberg,[11] and by Bullowa and Gottlieb,[12] in different animals by the use of x-rays after experimental procedures, and, more recently by Hudson, with motion pictures. This movement, undoubtedly, is engendered by the bronchial musculature. It has been demonstrated only in the tubes of size sufficiently large for roentgen observation, but there is no reason to suppose that it is not also found in the smaller tubes, even to the ramifications of the pulmonary lobule. It must be looked on as an important safety mechanism of the lung, and it is probable that it is of invaluable aid in ridding the air passages of exudate, as in the later stages of pneumonia. This movement is

11. Reinberg, S. A.: Roentgen-Ray Studies on Physiology and Pathology of the Tracheo-Bronchial Tree, Brit. J. Radiol. **30**:451, 1925.

12. Bullowa, J. G. M., and Gottlieb, C.: Roentgen-Ray Studies of Bronchial Movements, Am. J. M. Sc. **160**:98, 1920; Additional Experimental Studies in Bronchial Function, Laryngoscope **32**:284 (April) 1922.

said to be increased in gangrene and abscess of the lung, and to be diminished in bronchiectasis, where the muscle is degenerate. It undoubtedly acts in association with the cilia and with coughing. There has been demonstrated, too, by experimental procedures, a similar peristaltoid movement, going on constantly but unobstrusively, under ordinary conditions, and seeming to act in gently wafting air outward. The true meaning of this is not known. Is it the same movement as that more forcible peristaltoid action which removes exudates? It would seem closely related.

Other suggestions of uses for the bronchial musculature, particularly the more peripheral portions of this, have been made. For instance, it has been thought that, in some way, it might regulate the air tension in the alveoli. In the porpoise, Wislocki [13] (who kindly allowed me to read his unpublished manuscript) has recently shown that the sphincteric rings in the lobule are heavy, and can, apparently, close completely, thus locking air in the terminal chambers and preventing it from being forced out by the heavy external pressure to which the lung is subjected when the animal dives deeply. But this, as Wislocki properly observed, must be looked on as a special adaptation on the part of the porpoise. It does not seem at all likely that, in the land mammals, the rings of muscle in the walls of the alveolar ducts close at the end of inspiration; rather it would seem that they remain wide open.

Another function suggested is that of control of the airflow in the bronchial tree, like that of blood in the arterial system. It might be thought, for instance, that by relaxation of the system in certain parts, and contraction in others, the air might, under the control of the broncho-motor nerves, be diverted to special areas of the lung in the same way that blood is diverted through the action of the vasomotor nerves on the arterioles. This must be regarded as a speculation, at present. Though we know that much of the lung, under conditions of quiet breathing, is at rest, there is nothing to show that the air tubes in these quiescent parts are closed off through muscle contraction. It has been suggested, too, that indirectly the bronchial musculature may influence the blood flow in a somewhat similar manner, and that it may in this way, in some measure, have the effect of a vasomotor system.

Nervous Control.—The bronchial musculature is richly supplied with nerves, both from the vagus and from the sympathetic systems, and has both dilator and constrictor fibers. The vagus has long been looked on as a bronchomotor nerve, and its ramifications extend to the uttermost reaches of this motor system. It undoubtedly carries broncho-

13. Wislocki, G. B.: On the Structure of the Lungs of the Porpoise (Tursiops truncatus), Am. J. Anat. **44**:47 (July 15) 1929.

constrictor fibers, and probably bronchodilators also. The functional character of the fibers varies in different species.

As for the afferent impulses from the muscles, there are those who regard the vagus as carrying some, at least, of these, and also those who deny such a rôle to this nerve. The sympathetic is also looked on as carrying afferent impulses. The literature on the subject of bronchial innervation is extensive, and references may be obtained in my original article. Through the action of this system of nerves the various movements of the bronchial musculature are controlled, and the volume of the dead space influenced.

That there is an elaborate system for coordinating the action of this musculature in the various movements described there can be no doubt. It is probable, too, that the functional condition of this motor organ, whether in relaxation or contraction, is made known to the central nervous system, and appropriate reflex action initiated, not only within the lung, but also in the thoracic wall and floor, i. e., in the muscles of inspiration. In this way, probably, there is brought about a coordination between the intrapulmonary and extrapulmonary respiratory motor systems. When the intercostal muscles and diaphragm contract, and air enters the lung, the bronchial musculature may be assumed to relax; and, on the other hand, when the chest wall and floor relax, and when air is leaving the lung, there may be a reflex and orderly contraction of the musculature of the bronchial tree. Here is an interesting suggestion of an antagonistic action on the part of the intrinsic muscle of the lung in cooperation with the motor mechanism of the thorax that will bear further study.

PHARMACOLOGY AND PATHOLOGY

Pharmacology.—The enormous and important literature on the action of drugs on the bronchial musculature must be passed over briefly. The drugstuffs may be divided into the constrictors and the dilators. Five types of constrictors have been recognized, depending on their site of action, i. e., (1) on the vagus endings; (2) on the muscle itself; (3) on the sympathetic, producing inhibition; (4) on the central nervous system, and (5) on some unknown site. Most of these classes have numerous members. As for the bronchodilators, there are some seven types, as follows: (1) acting on the sympathetic nerve endings; (2) inhibiting the vagus; (3) acting on the ganglion cells; (4) acting on the muscle directory; (5) showing a reversible type of action; (6) showing a double action, constriction followed by relaxation; and (7) those with an unknown site of action.

The action of epinephrine is interesting, because it has been held that, in asphyxia, it is liberated in increased amounts and it may thus,

through its bronchodilator action, be the active instrument in a safety mechanism, facilitating the air inflow in this emergency.

Pathologic Changes.—Much has been written on the changes in the musculature in pathologic states. The spasm of asthma has been referred to; it may be that this is relieved, in some cases, automatically by the physiologic outpouring of epinephrine. Hypertrophy of the bronchial muscle has been found at autopsy. In anaphylaxis, too, we have in animals showing a rich bronchial musculature a liability to anaphylactic phenomena centering in the lungs. Hypertrophy of the bronchial musculature has also been found in many other pathologic conditions, as brown induration of the lung, parasitic infections, desquamative pneumonia, etc. Atrophy has also been described, as in bronchiectasis and emphysema, though, in cases of the latter, hypertrophy has been found.

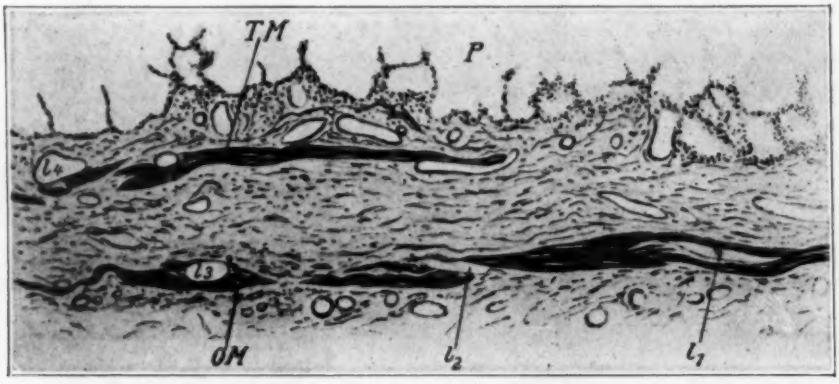

Fig. 19.—(From Baltisberger, abb. 16, p. 278.) Drawing from a section of lung of human being, showing the interstitial muscle in the visceral pleura. The dark strands are muscle. *OM* indicates the superficial layer of musculature; *TM*, deep layer; l_1 to l_3, lymphatics of superficial plexus; l_4, lymphatics of deep plexus; *P*, parenchyma of lung.

INTERSTITIAL MUSCULATURE

The system of fine wisps of muscle lying outside of the walls of the bronchial tree, known as the interstitial musculature of the lung, has been referred to. These filaments are seen in the interlobular septums, in the bronchial and vascular sheaths, and in the visceral pleura. This muscle is inconspicuous in any one point, but when considered in its entirety it forms an appreciable tissue element in the lung. A specimen from the visceral pleura is shown in figure 19. The function of these scattered fibers is not known, but may be assumed to be associated closely with that of the musculature of the bronchial tree.

CONCLUSION

This broader conception of the bronchial musculature may be of help in attacking problems centering in the lungs, as those of pneumonia, tuberculosis, or the sudden phenomenon of massive collapse, or atelectasis, which has recently been written on at great length by a number of workers, and discussed at this meeting. There seems reasonable ground for assuming that this condition may be associated with a contraction of the bronchial musculature. With the reawakening of interest in this important motor organ, we may expect much new information of a practical character regarding its functions in the healthy lung, and its derangements in the pathologic organ.

CIN-EX CAMERA STUDIES OF THE TRACHEO-BRONCHIAL TREE *

W. A. HUDSON, M.D
AND
HANS A. JARRE, M.D.
DETROIT

The Cin-ex camera is an apparatus designed to secure rapidly serial roentgenograms on film bands with the hope of obtaining physiologic records along with the anatomic records. Dr. Jarre has had the procedure in mind for several years, but, only recently, our desire to record, if possible, changes in contour and size of the tracheobronchial tree during respiration, has led to the development of the apparatus which Dr. Jarre named the "Cin-ex camera." We have endeavored to make successive records of functional changes at such short intervals as would enable us to interpret the motor phenomena themselves rather than to produce a true moving picture. The apparatus, together with some of the studies conducted up to that time, was presented to the staff of the Grace Hospital and the Detroit Roentgen-Ray Society on April 19, 1929, and will be described in detail in the roentgenologic literature. We are somewhat reluctant about promising too many advantages from the use of this method of study, but, as we hope to point out, we feel that there are certain definite advantages to be had from its use. The value depends on the manner in which the method is applied and on the proper interpretation of the results. In our studies of the tracheobronchial tree, we have undertaken to apply this method of study to one of the more difficult subjects.

Numerous observations have been recorded that would indicate the presence of a complex peristaltic action in the tracheobronchial tree. Chevalier Jackson [1] has repeatedly described a widening and narrowing of the bronchi as observed through the bronchoscope, and we are certain that all endoscopists have observed these changes. These are best illustrated by Dr. Jackson's drawings to show the effects of these motions on the relationship of a peanut in the bronchus to the walls of the bronchus during inspiration and expiration; that is, the presence of forcep spaces during inspiration and their absence during expiration.

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* From the Divisions of Roentgenology and Thoracic Surgery of the Grace Hospital.

1. Jackson, Chevalier: Bronchoscopy and Esophagoscopy, ed. 2, Philadelphia, W. B. Saunders Company, 1927.

In 1920, Bullowa and Gottlieb [2] studied the tracheobronchial tree in dogs under the fluoroscope and by means of roentgenograms after the injection of the bronchial tree with an opaque medium. They described: (1) a bellows-like action of the trachea and bronchi (dogs under anesthetic) which may be limited by contraction of the bronchial muscles and (2) a peristaltic action of the bronchial muscles which seemed to be adequate to empty the bronchi without involving ciliary motions.

In 1922,[3] they continued their observations by cauterizing the bronchial walls, thus severing the musculature, and they found that this interfered with the emptying of the bronchus thus treated. They regretted that they were not able to record frequently pictures with the x-rays so as to catch the changes due to motion.

Heinbecker [4] showed by the use of injections of iodized poppy seed oil 40 per cent into the bronchi that a wider shadow is cast by the larger bronchi at the end of full inspiration than at the end of full expiration.

Reinberg [5] described a peristaltic wave which he said resembles that seen in the intestinal tract.

William Shaw Miller,[6] after a long painstaking study of the anatomy of the musculature of the tracheobronchial tree, found that the bronchial musculature is arranged in a network of geodesic bands which prevent any tangental motion and in this way provides for the greatest amount of extension and contraction of the bronchi.

The muscle [7] bands form a sphincter about the openings of the alveoli into the bronchioli respiratorii and ductuli alveolares and also about the openings of the atria. He concluded that the action of the bronchial muscle in expiration is active and not passive, and he remarked that its action in the regulation of the tension of the air within the atria and air sacs deserved more attention.

Macklin [8] studied the elastic membrane of the tracheobronchial tree and concluded in 1922 that (1) the bronchial tree stretches during inspiration and contracts during expiration, the greatest excursion being at the terminal extremities of the limbs; (2) that with a rigid tube, like a gas pipe, expansion and contraction would be impossible and (3) that

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2. Bullowa, J. G., and Gottlieb, C.: Roentgen Ray Studies of Bronchial Function, M. Rec. **97**:251, 1920.

3. Bullowa, J. G., and Gottlieb, C.: Additional Experimental Studies in Bronchial Function, Laryngoscope **32**:284, 1922.

4. Heinbecker, P.: J. Clin. Investigation **4**:459, 1927.

5. Reinberg, S. A.: Brit. J. Radiol. **30**:451, 1925.

6. Miller, William Shaw: Harvey Lectures, 1924-1925; Am. Rev. Tuberc. **11**:1, 1925.

7. Miller, William Shaw: Am. Rev. Tuberc. **5**:689, 1921-1922.

8. Macklin, C. C.: Anat. Record **24**:119, 9122.

the main stem bronchi possibly shift forward and outward in inspiration, thus providing for expansion of the vertebral and mediastinal region of lung tissue.

Macklin did not feel, at that time, that the view of Miller,[7] and Keith,[9] that there occurs a widening and narrowing movement at the angles between diverging bronchi, had been clearly demonstrated. In later observations, in which he made roentgen studies, in full inspiration and full expiration on the same subject, he described the following motions: (1) elongation of the trunk and its branches during inspiration and a corresponding shortening of these structures during expiration; (2) dilatation of the bronchi during inspiration, narrowing during expiration; (3) a downward motion of the lower end of the trachea, and

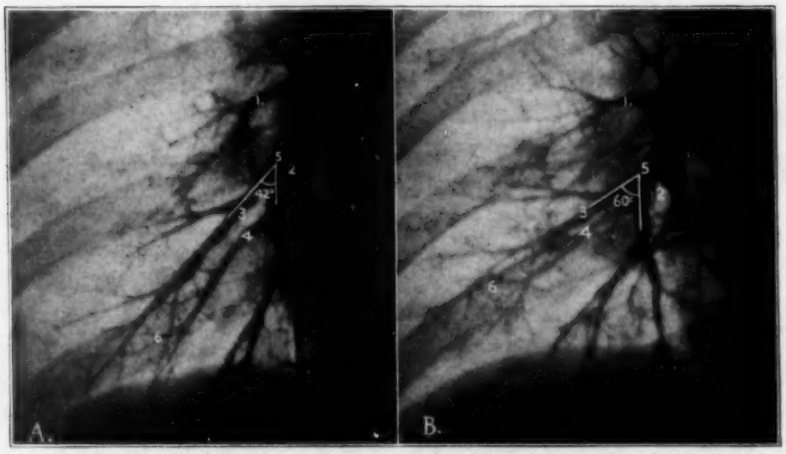

Fig. 1.—Normal right lower bronchus, mapped out by iodized oil, showing two extreme phases of one respiratory cycle, *A* indicating deep inspiration and *B* complete expiration. The following should be noted: *1*, difference in size and shape of the marked bronchus; *2*, effect of rotation on relationship of bronchi; *3* and *4*, approximation of the marked bronchi and differences in width and shape; *5*, angle changes from 42 to 60 degrees and *6*, separation and overlapping of the terminal bronchi during different phases of respiration.

main bronchi and lung root, in passing from expiration to inspiration, and an upward movement in passing from inspiration to expiration and (4) the interbronchial spaces show widening in inspiration without material alteration of direction of the bronchi.

In January, 1929, Macklin [10] gave a most extensive review of the literature on the musculature of the bronchi and lungs.

9. Keith, A.: The Mechanism of Respiration in Man; in Further Advances in Physiology, G. L. Hill, 1909.

10. Macklin, C. C.: Physiol. Rev. **9**:1 (Jan.) 1929.

In 1925, McClintock,[11] in a study of the anatomy of lobar pneumonia, concluded that the lung possesses a peristaltic mechanism.

Thus it will be noted that there have been ample observations to indicate the presence of motion in the tracheobronchial tree. There has been some variance in opinion as to the exact nature of this motion, and it remains for us to record the different phases of the motions before we can properly interpret them and set aside these variances.

We must warn physicians not to expect such striking motor phenomena in the tracheobronchial tree as can be observed in the stomach

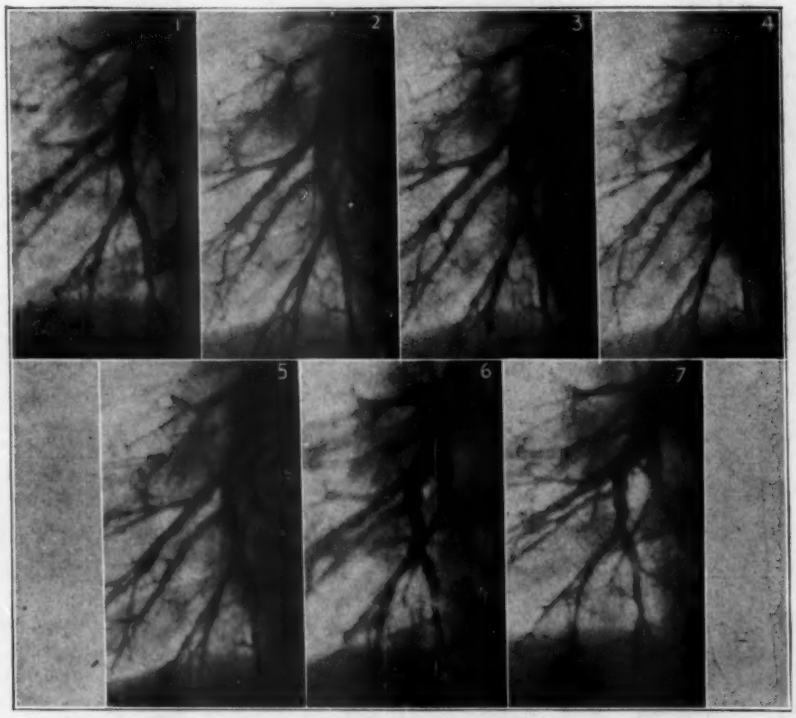

Fig. 2.—Demonstration of the functional behavior of a normal right lower bronchus (filled with iodized oil) during one respiratory cycle. (Section from a film-band 8 inches by 20 feet obtained with the Cin-ex camera.)

or intestines, as we are dealing with a smaller body of muscles and a smaller lumen in the object being studied.

It is obvious that the influence of this mechanism, when applied to a gaseous body, will be manifest in a manner different from that when it is applied to a liquid or viscid body. Again one might assume that the chief influence of any form of immobilization of the lung will be exerted

11. McClintock: Anatomy of Lobar Pneumonia, Michigan State M. J., 1925, p. 643.

on the passive elements of motion, while the active elements of bronchial motion will remain, and might in time compensate in part for the lost passive motion.

In our studies we first used a normal dog weighing about 10 Kg. We made a series of exposures at the rate of one per second, following which 10 cc. of iodized oil was allowed to flow into the tracheobronchial tree and the records continued. A difficulty encountered in this work was the rapid respiration in the dog. This led us to make studies on the human subject, who can regulate his rate of respiration. We have found this to be an advantage in that the slower rate of respiration permits more exposures during a single respiratory cycle.

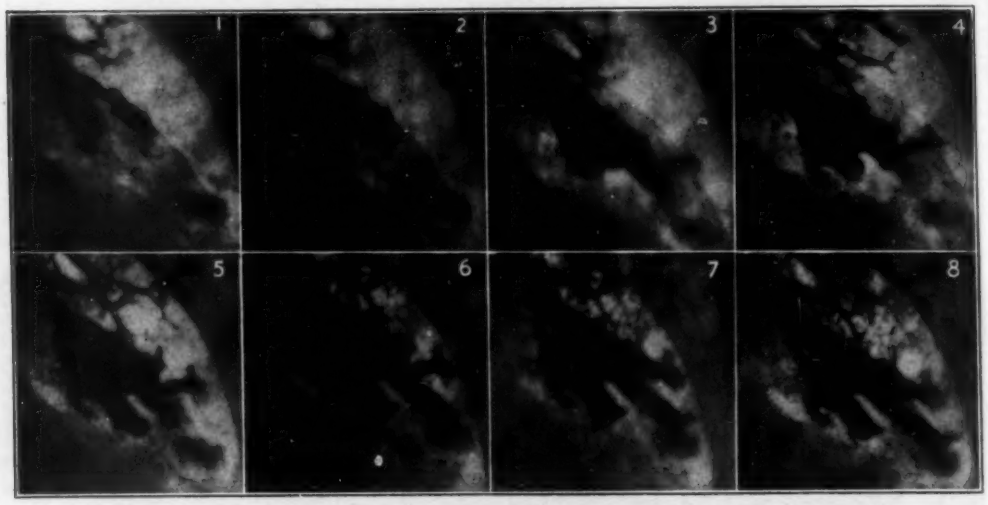

Fig. 3.—Demonstration of the functional behavior of an ectatic bronchus during respiration and gradual influx of iodized oil. (Sections from a film-band 8 inches by 20 feet obtained with the Cin-ex camera).

Serial x-ray pictures of the chest of a dog, made at the rate of one each second and with an exposure of one tenth of a second, revealed no abnormal markings, and it was particularly noted that the movement of the wall of the chest and the contents of the thorax during respiration caused no blurring of the pictures that interfered with the interpretation of the shadows present. The first series of x-ray pictures consisted of twenty-four exposures completed within twenty-four seconds from the time of the first exposure.

We next passed a small rubber catheter through the dog's laryngeal aperture into the trachea and made a second series, while 10 cc. of iodized oil was allowed to flow into the right stem bronchus. We have seen in this series of x-ray pictures that there occur regularly, along the

secondary bronchi, points of narrowing, this phenomenon being present chiefly during expiration; during inspiration, the walls become parallel to each other or nearly so. This phenomenon, as we have seen it in the dog, is not so clearly defined as we would like it to be. As the number of exposures which we were able to make during a respiratory cycle was limited by the frequency of the dog's respiration, we next turned our attention to the human being. We hoped that by so doing we might be able to secure more exposures during a respiratory cycle and to obtain more clearly defined evidence of motion inherent in the bronchi.

The first subject was a woman about 22 years of age. She was in good health and entirely free from any symptoms of pulmonary infection.

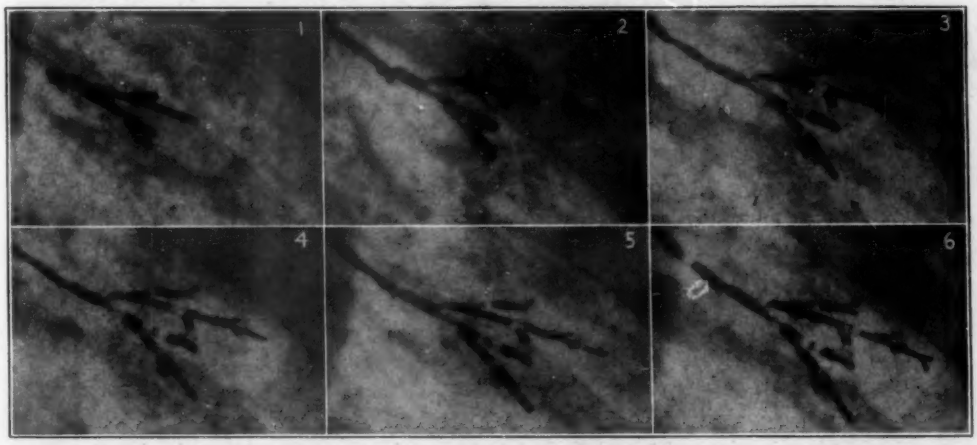

Fig. 4.—Demonstration of the functional behavior of an asthmatic-spastic-bronchus during respiration and gradual influx of iodized oil. (Sections from a film-band 8 inches by 20 feet obtained with the Cin-ex camera.)

Roentgenograms made immediately before the injection of iodized oil revealed no abnormal markings within the pulmonary field. Serial studies made while iodized oil was allowed to flow into the right stem bronchus through a catheter revealed a number of interesting facts:

1. There were noted regularly occurring narrowing, of all bronchis, which seemed to originate in the peripheral portions of the bronchial tree and to be associated with the propulsion of the oil toward the trachea. We also observed that this phenomenon was not of equal intensity in all parts of the bronchial tree at any one time. The regularity with which these narrowings occurred was such that one could determine the phase of respiration during which any given roentgenogram was made by their appearance. During inspiration the walls of the bronchi were

for the most part parallel and showed but few irregularities, while during expiration the walls lost their parallel relationship and just at the end of expiration seemed to come so closely together in some areas that they almost touched each other. We interpreted this phenomenon as evidence of a peristaltic-like action of the musculature of the tracheobroncheal tree. From its influence on the oil in the tracheobronchial tree it would seem that it was sufficient in itself to empty the bronchial tree of secretions under ordinary circumstances without invoking other aid.

2. We also saw in these studies an alteration of the angles of diverging bronchi of the lower lobes. During inspiration the angles became smaller, that is, of an acute nature, while during expiration they became greater. We noted changes in one angle from 41 to 81 degrees. The question immediately arises as to whether or not a rotation of the bronchial tree might not account for these changes in the angle. It is evident that rotation would cause apparent, but not true, alteration, in the size of the angles of diverging bronchi. At the same time, however, were the changes due to rotation, we would expect to see some angles become smaller while in another part of the field we would see the opposite. In these studies there was noted a uniform alteration of the angles in all parts of the field being studied. For this reason we feel that rotation is not sufficient to account for the changes noted.

3. Definite evidence of rotation of the tracheobronchial tree was seen. This was best brought out, in the lower lobes, by the appearance and disappearance of certain bronchi from the line of vision during the respiratory cycle. Rotation was seen to be from the back to the front during inspiration with a definite element of descent associated with the movement, so that the movement struck a curve simulating closely a corkscrew turn.

4. The tracheobronchial tree was seen to shift in a proximal distal direction during inspiration and in the opposite direction during expiration. The shift was over a distance of at least one-half inch, as determined by measurements taken from the last cervical spine to a point in the upper portion of the bronchial tree of the lower lobe, the shift being at least three times greater for those points in the most peripheral portions of the same lobe. We must bear in mind that this shifting of the bronchial tree is intimately associated with the rotation movement of the lung and that it, together with the rotation, undoubtedly plays a big part in providing space for expansion of the lung.

5. In addition, the bronchi, particularly those lying obliquely or parallel to the diaphragm, were seen to approach each other closely during expiration and to become widely separated during inspiration. The opposite was true of those bronchi which were perpendicular to the

diaphragm. In each case the movements closely simulated the opening and closing of a fan.

6. The position of the diaphragm and the position and relationship of the ribs during the different phases of respiration were recorded.

7. The influence of cough on the degree of bronchial spasm was seen, and it was particularly noted that a suppressed cough can force material into the alveoli, though in a normal person most of it enters the trachea.

It is evident that the foregoing demonstration of a motor phenomenon in the tracheobronchial tree will be of more value if we are able to show a practical application of the information obtained. There are certain conditions under which one might expect to find interference with this motor phenomenon. For instance, in those cases of pulmonary suppuration of long standing, particularly those spoken of as chronic bronchiectasis, we might expect to find that the action of the bronchial musculature has been, to say the least, inhibited. We accordingly made a study of such a case. A girl, aged 17, had a cough productive of large amounts of thick yellow sputum over a period of from ten to fourteen years. Bronchoscopic examinations showed the pus to be coming chiefly from the posterior portions of the left lower lobe. Serial studies revealed: a large gas pipe-like bronchus leading to the posterior lateral portion of the lower lobe in which no evidence of bronchial spasm was seen. In fact, with respiration, iodized oil seemed to accumulate in this area rather than to be forced out as in the normal lung. In the lung field, adjacent to this bronchus, some irregularities in the bronchial walls were noted that might be interpreted as bronchial contractions, but these were definitely inhibited. From these observations one might conclude that the grossly involved portion of the bronchial tree would require eradication before the patient could be freed of her symptoms, whereas those portions of the lung which show some evidence of remaining, physiologic motility might be treated more conservatively.

We also made studies on a man, weighing 170 pounds, who had been told by his clinician that he had asthma. We passed a bronchoscope on this patient and repeatedly encountered sufficient bronchial narrowing of a spastic character to make it difficult to enter the stem bronchi. At the same time we clearly demonstrated that the lumen of the bronchi was of sufficient caliber to take a 7 mm. and even a 9 mm. bronchoscope. Serial studies were made in the same manner as in the normal subject and we observed: A marked degree of bronchial spasm which prevented the oil from entering any of the terminal bronchioles. The spasm was seen to involve the entire bronchial tree so far as the oil had been permitted to enter and in addition to the general spasm of the bronchial tree we saw segmentation of the bronchi so that the secondary bronchi had an appearance similar to a string of sausages. It is apparent that with such a

degree of narrowing of the bronchial tree the patient will receive relief from his symptoms when the bronchial obstruction is relieved. It is not within our province today to discuss the manner in which relief is to be obtained.

In the animated films one observes the same changes in position, size and shape of the bronchi as brought out in the study of the film slides. As we said in the beginning, we did not begin the work with the idea of producing a true moving picture. However, the animated film does make the element of motion more strikingly evident to one spending but a few moments on the subject.

While we have been able to demonstrate definitely certain types of motion in the tracheobronchial tree, we feel that this is only the beginning of the study of this subject. We do not feel justified in forming conclusions at this time; but we have felt that we are justified in presenting these studies in order to make the method known. We shall without doubt find it necessary to add to and take from our impressions as we make further observations.

ABSTRACT OF DISCUSSION

ON PAPER BY DR. MACKLIN AND THAT BY DRS. HUDSON AND JARRE

Dr. E. A. Graham, St. Louis: As usual, after such a demonstration as this, I should like to add my praise. I think the society owes Dr. Hudson and his associate a vote of thanks for these pictures; also to Dr. Macklin for coming here and giving us the benefit of his extensive research, which has continued over a long period of years.

Dr. Cutler and I were both curious, Dr. Hudson, to know whether or not in taking any pictures of this last patient (I mean the patient with the spasm) you used any epinephrine or ephedrine and then took some more pictures; or have you done that on any asthmatic patients?

Dr. Hudson: That is one of our future problems, Dr. Graham.

Dr. C. C. Macklin, London, Canada: I wish to thank the association for the invitation to address you here, and I also wish to congratulate Dr. Hudson for his series of pictures. His views are illuminating to me, and I am sure they have brought to your minds a new conception of the changes which go on in the bronchial tree in the process of lung inflation and lung deflation.

There is one point I should like to bring up, and that is the necessity of dissociating accurately the behavior of the bronchial tree, on account of the presence in it of what one might call foreign substance, from its behavior due to normal respiratory action.

The work of such men as Bullowa and Gottlieb emphasizes the occurrence of peristaltoid action in the bronchial tree. I am just wondering how much of the change seen in these shadows is due to the effort of the bronchus to relieve itself of this oil.

Dr. William Hudson, Detroit: I have little to add, except that I should like to answer Dr. Macklin's question.

As I said in conclusion, there are a good many problems that will be coming up and that are already before us at this time. Dr. Graham has mentioned one of the problems. We hope to undertake immediately the study of the use of epinephrine and other drugs to see what their action is on this spastic bronchus.

The other is this condition in the extremely dilated bronchus, for instance. What would be the effect of a phrenicectomy on that patient, and the action of that bronchus? What would be the effect of draining that bronchus and allowing continued drainage over a long period of time so that the infection has disappeared, and then repeating the study to see if there is any return of the embolus of muscular contraction? We should see if the marshy area above there would return to a normal condition.

In reference to Dr. Macklin's question about the foreign substance, it was necessary to introduce some substance that could be visualized. It is not exactly an ideal situation, but it is the one which is most available and, as I pointed out in the beginning, it is evident that the influence of the mechanism as we have pictured it when applied to a gaseous body or to a liquid body or to a viscid body would be different in any one of those conditions. If we used an irritating gas, it is obvious that the mechanism, if present, would be called into more apparent workings.

Dr. Jarre has devoted a large amount of time to the development of the mechanism whereby we have been able to record these pictures. We have brought some of the original exposures on the film bands, which were made especially for us, and we should be glad to have you see them after the meeting is over.

THE PRODUCTION OF INTRAPULMONARY SUPPURATION BY SECONDARY INFECTION OF A STERILE EMBOLIC AREA

AN EXPERIMENTAL STUDY *

EMILE HOLMAN, M.D.
AND
MARY E. MATHES, M.D.
SAN FRANCISCO

In a previously described series of experiments,[1] it was found that the introduction into the venous circulation of an embolus infected with pyogenic organisms may be followed by widely differing pathologic changes in the parenchyma of the lung (fig. 1). Around the invading embolus there may occur a local consolidation and transient pneumonitis with complete and early recovery and with no permanent pulmonary damage. Hemorrhagic infarction may occur followed either by a cicatrizing resolution or by the formation of an abscess in the infarcted area. Occasionally, there develops a massive hemorrhagic consolidation of the lobe in which the infected embolus lodges, invariably followed by death.

In attempting to explain the varying results produced by identically infected emboli, differing degrees of thrombosis within the pulmonary vessels were postulated. If thrombosis should proceed only distally from the embolus, simple infarction might be expected, whereas thrombosis both proximal and distal to the embolus might lead to an extensive hemorrhagic consolidation of the entire lobe.

To amplify our observations and to confirm or to disprove the foregoing assumptions, experiments were undertaken to determine the exact conditions present within the pulmonary vessels following the simultaneous introduction of infected and sterile emboli into the same animal.

The unexpected development of an infarction and an abscess in sterile embolic areas, due to a bacteremia from the infected embolus, led to other experiments involving two sterile jugular emboli followed or preceded by the introduction of bacterial emulsions into the femoral vein. Again abscesses occurred in the sterile embolic areas.

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* From the Laboratory for Surgical Research, Stanford University Medical School.

1. Holman, E.; Chandler, L. R., and Cooley, C. L.: Experimental Studies in Pulmonary Suppuration, Surg. Gynec. Obst. **44**:328 (March) 1927.

METHOD

The experiments were performed on dogs under ether anesthesia. The embolus was prepared as originally described for the production of pulmonary abscesses.[2] The jugular vein was isolated, two segments excised and identically prepared, except that one contained one lead shot and was infected with *Staphylococcus aureus, Streptococcus nonhemolyticus* and *Bacillus coli,* whereas the other segment of vein contained one and one-half pieces of lead shot and was sterile. The three aforementioned strains of organisms were maintained at approximately unvarying virulence by subcultures, and the same strains were used throughout. The sterile embolus was introduced into the proximal end of the divided jugular

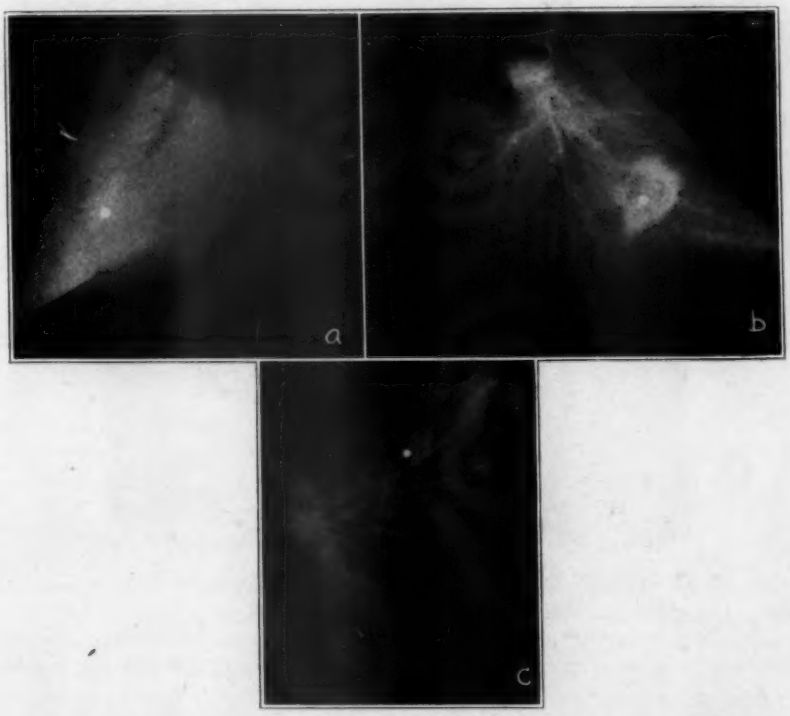

Fig. 1.—Roentgenograms of excised specimens to show the varied effects of infected jugular emboli: *a,* complete hemorrhagic consolidation with death after four days; *b,* infarction and abscess formation after nine days; *c,* complete restoration of lung to normal after sixty-three days.

vein first, and the animal was kept on one side for about ten minutes, during which time the thorax was occasionally shaken to insure the onward progress of the embolus through the heart and thence into the lungs. The animal was then turned to the other side and the infected embolus introduced. It was usually possible by this procedure to control the ultimate lodgment of the embolus in

2. Holman, E.; Weidlein, I. F., and Schlueter, S. A.: A Method for the Experimental Production of Lung Abscess, Proc. Soc. Exper. Biol. & Med. **23:** 266, 1926.

opposite pulmonary fields, and the subsequent identification of the emboli was made possible by the differences in the shot.

The animals were killed at varying periods and the condition of the pulmonary circulation investigated by injecting Hill's mass,[3] which is a suspension of 17 per cent bismuth oxychloride in a 10 per cent solution of gum acacia. This mass fills the arterial tree down to, but not including, the capillary bed. The thorax was opened exactly in the midline of the sternum, and the descending aorta beyond the third intercostal was ligated, as were also the right innominate, the left subclavian, the left carotid and both vertebral arteries. These ligations permitted the complete injection, at a pressure of 160 mm. of mercury, of the bronchial arteries through a cannula introduced into the ascending aorta. The lungs and heart were removed en masse, the lungs were inflated and kept inflated by an intrabronchial pressure of 10 mm. of mercury. Roentgenograms of the injected bronchial arteries were made. Then Hill's mass was injected into the pulmonary artery, at a pressure of 60 mm. of mercury, the lung being kept inflated during and after the injection. Again roentgenograms were made.

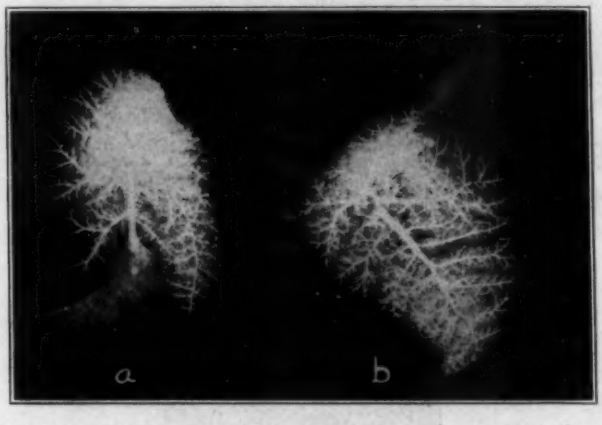

Fig. 2 (Animal K 6).—Roentgenograms of the isolated lobes twenty-four hours after the introduction of jugular emboli: *a*, infected embolus with pneumonitis surrounding it completely occluding the pulmonary artery; *b*, sterile embolus with no reaction about it but complete occlusion of the pulmonary artery.

PROTOCOLS

The following protocols illustrate our results:

Animal K 6.—On Sept. 5, 1928, two emboli, the first one sterile and the second one infected, were introduced into the jugular vein. Twenty-four hours later, the animal was killed with chloroform. At necropsy, the pleural cavity was clear, without adhesions. The upper lobe contained a segment involving almost a third of the lobe, which was firm, edematous and red with extravasated blood, evidently an infarction produced by the infected embolus. There was no evidence on the surface of the sterile embolus, the remainder of the lung appearing normal. The injected specimen (fig. 2) showed that the sterile embolus had lodged in the right upper lobe occluding a second degree branch of the pulmonary artery. A similar

3. Hill, Eben: A Radiopaque Bismuth Suspension for Anatomical and Pathological Research, Bull. Johns Hopkins Hosp. **44**:248 (April) 1929.

occlusion had been produced in the left upper lobe by the infected embolus, the artery being occluded for about 1 cm. proximal to the embolus by a retrograde thrombosis. On cut section, the lobe containing the sterile embolus showed no reaction about the shot, whereas the lobe with the infected embolus showed a mottled, yellowish-brown and red area extending out to the periphery from about the center of the lung. There was no abscess, but a marked pneumonitis and a hemorrhagic infiltration of the parenchyma surrounded the shot for several centimeters.

ANIMAL K 19.—On November 7, two emboli were introduced into the jugular vein, the one sterile and the other infected. Within eighteen hours the temperature had risen from 35.5 to 41.5 C., the pulse rate from 144 to 180 and respirations from 28 to 64. The dog died twenty-four hours after the introduction of the emboli. At necropsy, the left pleural cavity contained considerable purulent bloody fluid. The left lower lobe, which contained the infected embolus, showed an extensive hemorrhagic consolidation, although part of the lobe was still air-containing. The right upper lobe contained the sterile embolus, but there was no evidence of its presence until the pulmonary artery was injected, when it was sharply outlined by its lack of injection.

A blood culture made after the death of the animal showed a growth of all three organisms contained in the infected embolus, namely, *Staphylococcus aureus, Streptococcus nonhemolyticus* and *Bacillus coli.*

The injection of the bronchial artery showed no dilatation, and the pulmonary artery showed good injection up to within 1 cm. of the infected embolus. There was no injection of the pulmonary artery beyond either the sterile or the infected embolus.

There was a hemorrhagic consolidation of a portion of the left upper lobe contiguous to the consolidated lower lobe. This pneumonic area in the left upper lobe showed good injection of the pulmonary artery.

Two other animals, K 7 and K 21, both of which died forty-eight hours after the introduction of the emboli, showed a hemorrhagic consolidation of the lobe containing the infected embolus, and the pulmonary artery in each instance showed good injection up to within 1 cm. of the embolus. Moreover, in all three instances, a massive consolidation occurred in other lobes besides those containing the emboli and a good injection of the pulmonary artery in these lobes was obtained.

ANIMAL K 22.—On Nov. 19, 1928, a sterile and an infected embolus were introduced as already described. Twenty-four hours later the temperature had risen from 35.6 to 39 C., the pulse rate from 112 to 136 and respirations from 20 to 32. The dog was killed with chloroform four days after the introduction of the emboli. At necropsy, the left lower lobe contained a pyramidal-shaped area of liver-like consistency, which showed on the surface as a bright red, slightly depressed area. There was no evidence of the sterile embolus on either palpation or inspection.

A roentgenogram made after the injection of the bronchial artery showed both emboli in the left lower lobe with a marked consolidation and beginning abscess formation around the infected embolus and no change about the sterile embolus (fig. 3). There was beginning dilatation of the artery leading to the infected embolus, but dilatation was absent in the branch leading to the sterile embolus. The roentgenogram made after the injection of the pulmonary artery showed almost complete filling of the bronchial and alveolar spaces in this lobe due to a communication between a bronchus and the pulmonary artery at the site of the

abscess. A cut section through the lobe showed a small abscess lying at the apex of a wedge-shaped triangular area of hemorrhagic infarction. There was no reaction about the sterile embolus.

ANIMAL K 20.—The usual two emboli were introduced, and the animal killed eight days later. At necropsy, the left lower lobe, in which lay the infected embolus, contained a firm section 2 cm. in diameter, presenting on the surface as a red, slightly depressed area. The right lower lobe contained the sterile embolus, as disclosed on the surface by a pyramidal-shaped area slightly paler than the rest of the lung.

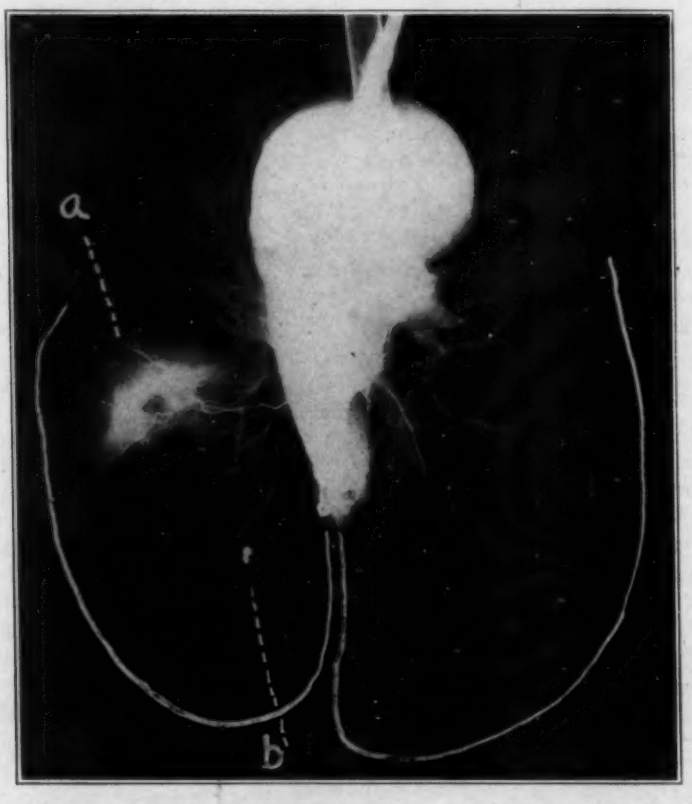

Fig. 3 (Animal K 22).—Roentgenogram of the entire lung following injection of the bronchial artery four days after the introduction of jugular emboli: *a*, marked pneumonitis with small abscess formation about the infected embolus; *b*, no reaction about the sterile embolus. Note the normal size of the bronchial artery leading to the sterile embolus, and the beginning dilatation to the infected embolus.

The roentgenogram taken after injection of the bronchial artery showed a remarkable dilatation of the bronchial artery leading to the lobe containing the abscess (fig. 4). In the region of the abscess there was demonstrated a definite anastomosis between the bronchial artery and the pulmonary artery, as shown by a localized injection of the latter through the former. A definite dilatation, though not so marked, also characterized the bronchial artery leading to the sterile

embolus. Aside from the slight injection through the bronchial artery as previously noted, the pulmonary artery beyond either embolus was not injected.

The cut section showed a large abscess, 2 by 1.5 cm., produced by the infected embolus, whereas the sterile embolus was embedded in intact pulmonary tissue which showed a slight edema and slight hemorrhagic infiltration in a pyramidal-shaped area beyond the embolus.

ANIMAL K 17.—On October 9, this animal received two emboli, according to the usual procedure. Four days later, the temperature had risen from 37.2 to 40.3 C., the pulse rate from 88 to 168 and respirations from 16 to 76. The animal was killed eight days after the introduction of the emboli. At necropsy, the pericardium was red and covered with a fibrinous exudate. The parietal pleura was also covered by a fibrinous exudate. There was a small amount of free turbid fluid in the left pleural cavity. The left upper lobe, which contained the infected

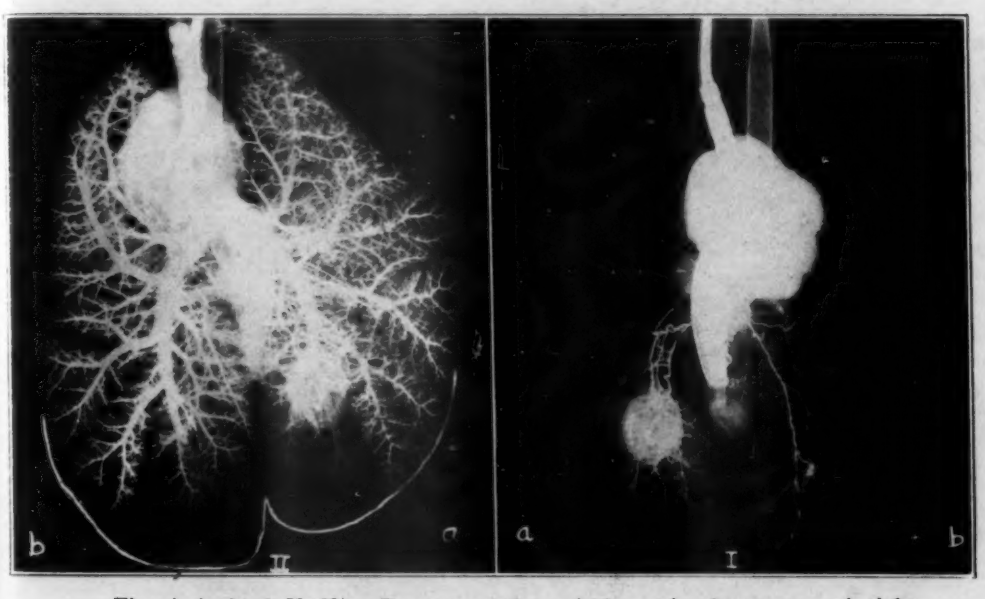

Fig. 4 (animal K 20).—Roentgenograms of the entire lung removed eight days after the introduction of jugular emboli: I, following injection of the bronchial artery; II, following injection of the pulmonary artery. Note the greater dilatation of the bronchial artery to the lobes containing the infected embolus (*a*), as compared with the artery leading to the sterile embolus (*b*). There is a slight injection of the pulmonary artery through the bronchial artery, in the region of the abscess.

embolus, was closely adherent to the mediastinum and showed an extensive gangrenous area with considerable destruction of pulmonary tissue. A small part of the lower portion of the lobe was still air-containing.

The right middle lobe, which contained the sterile embolus, showed a typical hemorrhagic infarction, comparable to the infarction produced by an infected embolus. The infarcted area was firm, deep red and nonair-containing. The bronchial artery leading to the gangrenous area was again markedly dilated, with slight but definite dilatation of the artery to the infarcted area due to the sterile embolus (fig. 5). The pulmonary artery was injected up to the location of the

emboli, but not beyond them. The cut section showed marked destruction of pulmonary tissue beyond the infected embolus, and a typical hemorrhagic infarction beyond the sterile embolus.

Before death, a blood culture in this animal was positive for all three organisms originally introduced in the infected embolus. It may be inferred, therefore,

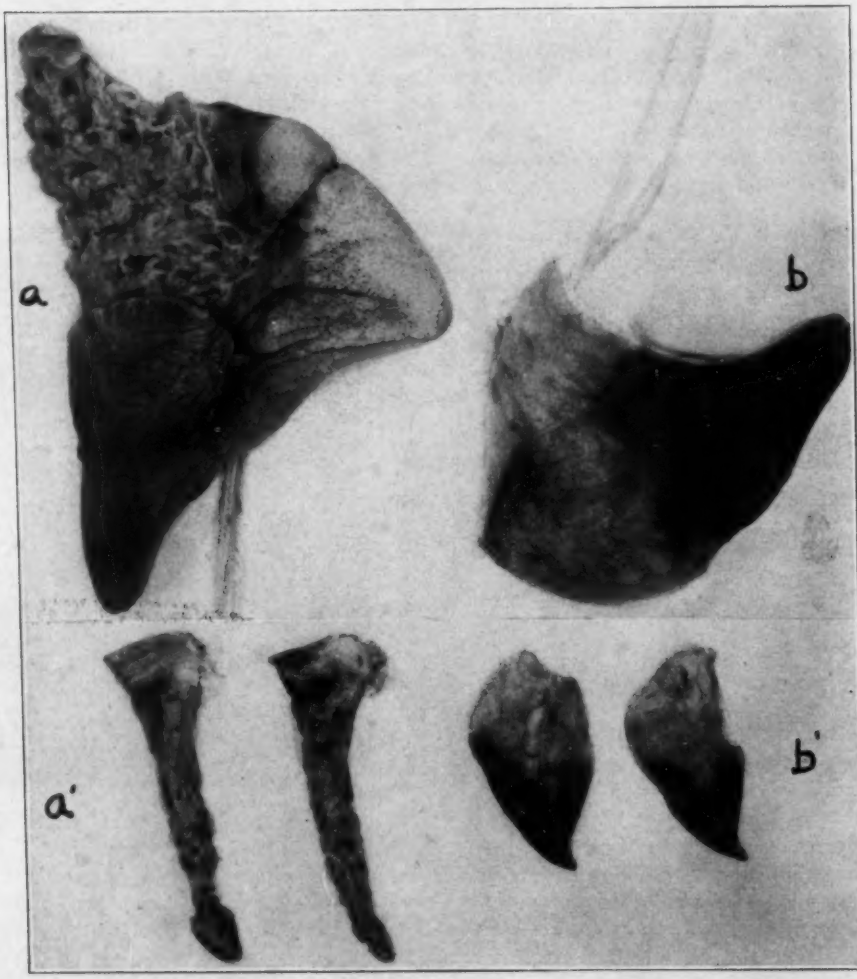

Fig. 5 (animal K 17).—Isolated lobes removed eight days after the introduction of jugular emboli: *a*, gangrene and multiple abscess formation distal to the infected embolus; *b*, hemorrhagic infarction distal to the sterile embolus; a^1 and b^1 show the cut sections.

that the hemorrhagic infarction caused by the sterile embolus was due to secondary invasion of the embolic area by circulating organisms.

ANIMAL K 18.—Two emboli, one infected and one sterile, were introduced in the usual manner on November 7, and the animal killed fifteen days later. At necropsy there were no adhesions or fluid in the pleural cavity. In the left lower

lobe, which contained the infected embolus, there was a scarred area about 4 by 2 cm. in size, firm, deep red and somewhat depressed after inflation of the lung. Before inflation, the site of the sterile embolus could not be detected, but after inflation the right upper lobe showed a pyramidal-shaped area, slightly paler than the rest of the lobe. Injection of the bronchial artery showed moderate dilatation of both branches leading to the lobes containing the emboli, and less marked in the lobe containing the sterile embolus.

There was a slightly increased density about the infected embolus, but the pulmonary field around the sterile embolus was normal. The pulmonary artery showed filling up to both emboli, but not beyond them. The cut section of the lobe containing the infected embolus showed no abscess cavity, but the pulmonary tissue beyond the embolus was slightly discolored by blood pigments and was definitely more fibrous than the normal lung. The embolic area beyond the sterile embolus was normal.

Comparable observations with almost complete return to normal of the lung beyond the infected and sterile emboli were made in three other animals: K 11 (twenty-four day specimen), K 12 (twenty-seven day specimen) and K 35 (ninety day specimen).

ANIMAL K 26.—Two emboli, one infected and one sterile, were introduced into the jugular vein on December 3. Four days later the animal was very ill with a fever of 40.4 C., a pulse rate of 136 and respirations 56. The animal remained quite ill until it was killed fifteen days after the introduction of the emboli.

At necropsy, there was a small amount of slightly cloudy blood-stained fluid in each pleural cavity. The pericardium was thickened, red and furry on its pleural surface. In the left lower lobe, which contained the infected embolus, there was a well defined, firm, dark red segment, with ulceration of the visceral pleura due to destruction of underlying pulmonary tissue. The cut section showed multiple abscesses in this area (fig. 6).

Similarly, in the right lower lobe, which contained the sterile embolus, there was a firm, dark red section, also ulcerated on its surface with several small fluctuating abscesses presenting on the surface. On cut section, one large abscess and several smaller abscesses were present. The bronchial artery was greatly dilated in the branches leading to the lobes containing the emboli, the pulmonary artery being uninjected beyond the emboli. There was apparently a thrombus in the pulmonary artery 2 cm. proximal to the infected embolus.

Again the development of abscesses in the embolic area beyond the sterile embolus can be explained only on the basis of secondary invasion of this area by circulating organisms liberated by the infected embolus. A blood culture two days after the introduction of the emboli was sterile. Unfortunately no other cultures were made, but from previous experiences[1] one may infer the presence of a bacteremia due to the abscess produced by the infected embolus.

ANIMAL K 25.—On Dec. 3, 1928, two emboli, one infected and the other sterile, were introduced into the jugular vein. Three days later the animal was quite ill, the temperature having risen to 40.6 C., the pulse rate to 160 and respirations to 56. A blood culture was positive for nonhemolytic streptococcus. Thereafter there occurred a gradual improvement, but with the loss of considerable weight and a persistent cough. After thirty-one days, the animal appeared normal and was killed. At necropsy, the left lower lobe was firmly adherent to the diaphragm and to the wall of the chest. Within the lobe at the site of these adhesions was a large, rounded, firm area, 4 cm. in diameter, which proved to be the location of the infected embolus (fig. 7). After inflation, the left lower lobe showed marked retraction and diminution in volume. The location of the sterile embolic

area was disclosed by a slightly paler color to the surface of the tip of the right upper lobe. The left upper lobe, contiguous to the lower lobe, showed a red retracted area, undoubtedly the site also of a localized pneumonitis. This involvement of a lobe adjacent to an infected area in another lobe has been frequently noted and its explanation is still wanting.

The bronchial artery leading to the lobe that contained the embolus was enormously dilated, forming a thick network of vessels around the bronchus and completely surrounding the abscess cavity which had a diameter of about 2.5 by 3 cm. The pulmonary artery showed no filling beyond either embolus.

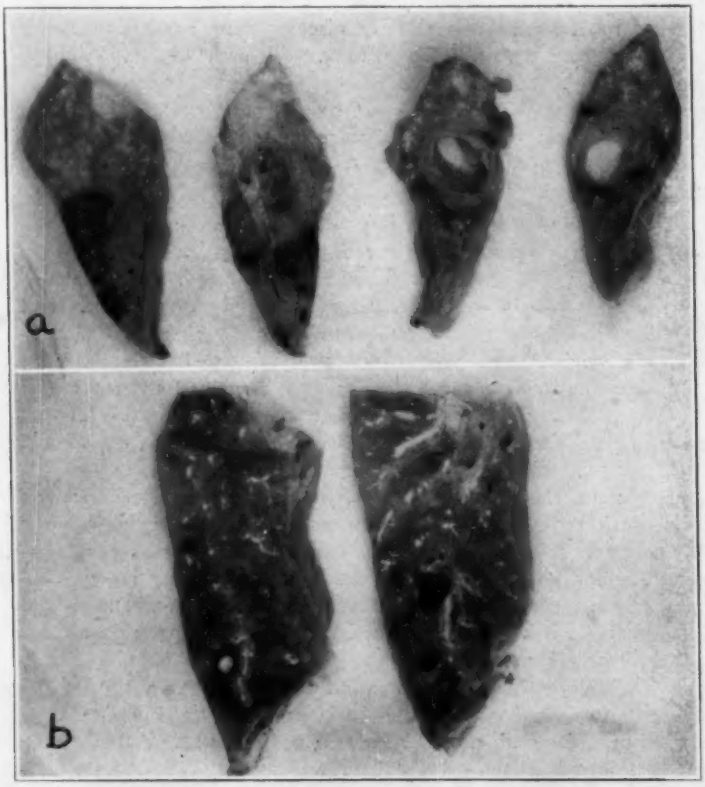

Fig. 6 (animal K 26).—Cross-sections of lobes removed fifteen days after the introduction of jugular emboli: *a*, mottled infarction and multiple abscesses distal to the sterile embolus; *b*, multiple abscesses distal to the infected embolus.

The cut section showed a large multilocular abscess with little inflammation in the lung surrounding it, and with no communication to a bronchus. The lung around and beyond the sterile embolus was normal.

ANIMAL K 35.—This animal was killed ninety days after the introduction of a sterile and an infected embolus. The necropsy revealed an almost normal appearing lung in the deflated state, but after inflation the two embolic areas were revealed as being slightly paler than the lung proximal to the emboli.

The bronchial artery leading to the lobe containing the sterile embolus was dilated from four to five times its normal size. The pulmonary artery distal to

this same sterile embolus showed practically no filling. On the other hand, the bronchial artery leading to the lobe containing the infected embolus was about normal in size, and the pulmonary artery distal to the embolus was almost completely filled by the development of an extensive collateral circulation through anastomosing pulmonary vessels. The main pulmonary artery leading to the embolic area was still completely occluded by the embolus.

A cut section through the sterile embolic area showed the embolus surrounded by a fibrous thin wall and normal pulmonary tissue. A section through the infected embolic area showed no abscess, but a slight fibrosis of pulmonary tissue beyond the embolus.

Fig. 7 (animal K 25).—Inflated lung showing marked shrinkage and retraction of the lobe *a* containing the abscess produced by the infected embolus. The sterile embolic area at *b* was not detected in the deflated state, and presented only as a slightly paler area in the inflated state.

Comment.—A review of the experiments undertaken thus far shows the following results:

In eight normal animals that received simultaneously two sterile emboli into the jugular vein without any infecting organism, there occurred not a single instance of hemorrhagic infarction. Occasionally, on the surface of the embolic area, one observed a slightly paler color

than normal, and on cut section one noted a slight edema with an altered pigmentation, indicative of a hemorrhage into the pulmonary tissue.

A striking fact was the absence, in most instances, of all evidence of the site of the embolic area, due to the sterile embolus when the lung was examined in the deflated state. Usually, but not always, inflation to a normal degree of 10 mm. of mercury disclosed the location of the embolus by a slightly paler color of the surface of the lung distal to the embolus. The clinical importance of this observation is apparent when one considers that most pathologists examine the lung only in the deflated state, and undoubtedly many sterile embolic areas are therefore overlooked.

In a series of thirty-two animals that were killed more than four days after operation and that had received simultaneously one infected and one sterile embolus, hemorrhagic infarction and abscesses were produced by the infected embolus in all but four instances. In these four animals killed fifteen, twenty-four, twenty-seven and ninety days after the introduction of the emboli, there was evidence of an old hemorrhagic infarction which had undergone resolution and healing by fibrosis.

In the three animals that died within forty-eight hours after the introduction of the emboli, there occurred massive hemorrhagic consolidation of the lobe containing the infected embolus.

The thirty-two sterile emboli produced in all but two instances no more alteration in the pulmonary tissue than a slight edema and a slight hemorrhagic infiltration, and often there was no evidence that even these changes had occurred. In one animal, however, that received both an infected and a sterile embolus, there occurred not only an abscess about the infected embolus, but also a typical hemorrhagic infarction distal to the sterile embolus. Such an infarction was produced in other instances only by an infected embolus, and as this animal, in common with many other examples, showed a blood culture positive for all three organisms originally introduced in the infected embolus, we are justified in assuming that the embolic area became secondarily infected by organisms circulating in the blood stream. Similarly, in another animal, K 26, there occurred multiple abscesses, not only in the embolic area distal to the infected embolus, but also in the area distal to the sterile embolus, which presumably become secondarily infected by organisms circulating in the blood stream.

Acting on the observations made in these two instances, sixteen other animals received two sterile emboli each, followed at varying intervals by the intravenous injection of 1 cc. of a bacterial emulsion. In one animal (K 56), two sterile jugular emboli ware introduced, followed immediately by an injection into the femoral vein of a thin bacterial emulsion of *Staphylococcus aureus*. At necropsy, twenty-two days later,

an abscess was found containing one of the sterile emboli, whereas the lung in the region of the second embolus remained unchanged.

It is an arresting fact that in spite of a definite bacteremia intentionally produced following the introduction of the sterile emboli, there occurred only this one example of lowered resistance in the region of the embolus, as demonstrated by the formation of an abscess. Presumably the double blood supply to the lungs (3 and 4) is partly responsible for this protection, the prompt dilatation of the bronchial artery providing an adequate blood supply to the area deprived of the normal filling of the pulmonary artery.

This dilatation of the bronchial artery is undoubtedly of considerable clinical significance with reference to the concentration of the defense forces of the body around the infected part of the lung, and may account for the extraordinary ability of the lung to overcome and combat the evil effects of an infected embolus. Not infrequently one is greatly surprised by the ability of the lung to withstand an infection and to recover completely in spite of extensive destruction of pulmonary tissue. It is significant that infection about the sterile embolus occurred only when the bacteria were injected almost simultaneously with the introduction of the jugular emboli.

In two other instances, the bacteria were injected just prior to the introduction of the emboli. One animal died of an extensive bronchopneumonia in all parts of the lung, including the embolic areas. In the second animal, a hemorrhagic consolidation with destruction of pulmonary tissue and abscess formation occurred in the right lower lobe, which contained both sterile emboli. Our experiments on this phase of the study have not been completed.

That the embolic area beyond a sterile embolus may become secondarily infected, resulting in the production of an intrapulmonary abscess, is of considerable clinical and scientific importance. A sterile embolus may reach the lung from a clean operative wound or from a spontaneously developed thrombosis in the peripheral venous system. Infection of the resulting embolic area may occur from several sources: (*a*) from a transient bacteremia, (*b*) by direct extension from an intrabronchial infection and (*c*) by the lymphatics running through the area.

As an example of what may happen clinically, the two following occurrences in our laboratory are of more than passing interest.

ANIMAL K 59.—On February 25, an experimental cholecystectomy was performed on animal K 59, following which the abdominal wound became infected. Only a draining sinus remained on March 13, when an exploratory laparotomy was performed by students. Again the wound became infected.

Twenty-eight days later, in the presence of two abdominal wounds draining a small amount of pus, two sterile emboli were introduced into the jugular vein. Pus continued to drain from the wounds until the animal was killed twenty-two days later. At necropsy, with the lung in the deflated state (fig. 8), a small scar

was found on the pleura of the left lower lobe, underneath which a round firm area, 1.5 cm. in diameter, could be felt. In the same lobe a second smaller, rounded, firm area could be felt. After inflation, the lung appeared remarkably different (fig. 8). There was marked retraction of the left lower lobe with marked diminution in its volume. It is evident that the true pathologic state of a lung cannot be determined by examination of the deflated lung only.

A roentgenogram showed both emboli in this left lower lobe with marked reaction about one of them. The bronchial artery leading to both emboli was markedly dilated, and the pulmonary artery beyond the emboli was not filled except for a slight injection in the region of the abscess through the bronchial artery (fig. 9).

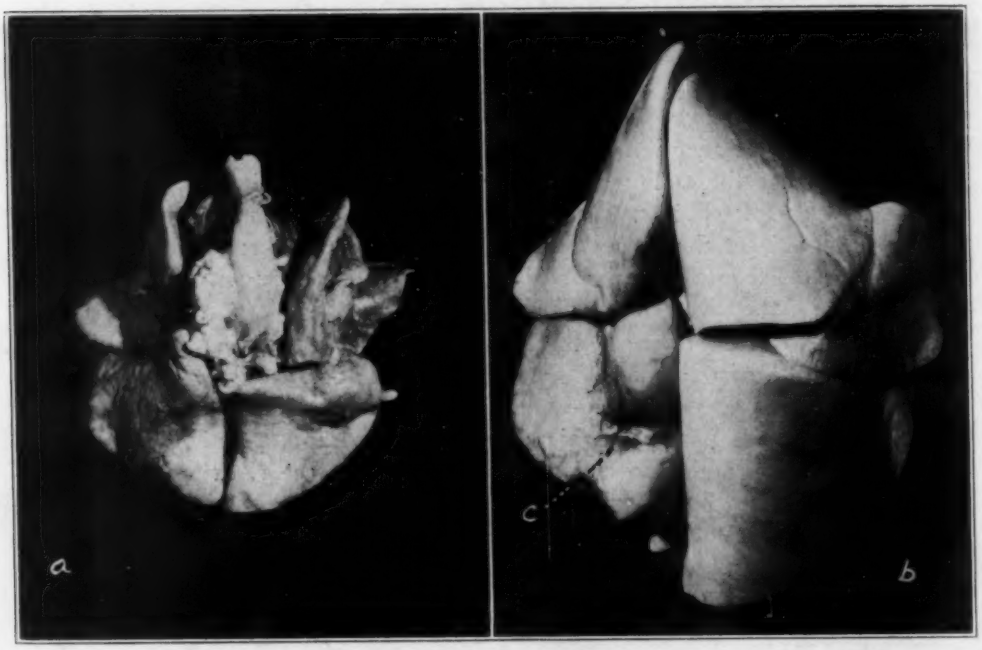

Fig. 8 (animal K 59).—Appearance of the uninflated lung (*a*) and the inflated lung (*b*) under a pressure of 10 mm. of mercury, showing the marked difference in the appearance of the lobes; *c*, abscess with marked retraction of the lobe in the region beyond a sterile embolus secondarily infected from an infected abdominal wound.

The cut section revealed a small irregular abscess cavity in which lay an embolus. Surrounding the cavity and extending to the visible depressed scar on the surface, there was a well defined area of consolidation. The second embolus was encapsulated by fibrous tissue, but otherwise there was no pathologic change in the pulmonary tissue around it.

ANIMAL R 49.—This animal was received at the laboratory with a compound suppurating fracture of the left hind leg. Aside from the open wound of the leg, the dog seemed well. On March 7, two sterile emboli were introduced into the jugular vein. The dog was killed eight days later, and at necropsy there was noted on the surface of the left upper lobe a deep red, softened area about

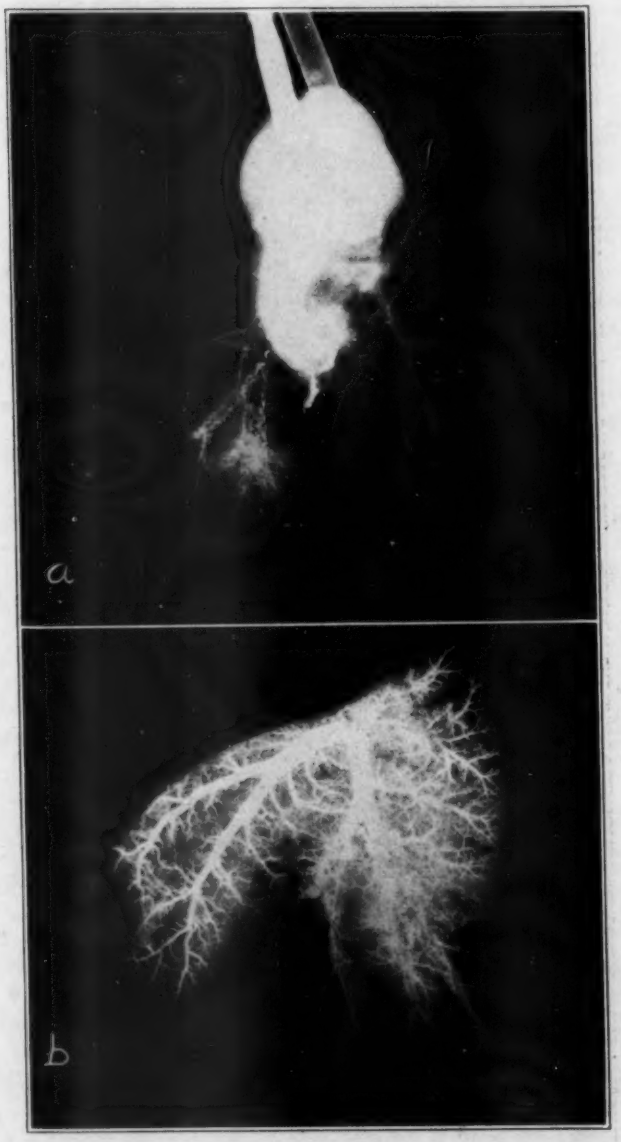

Fig. 9 (animal K 59).—*a*, injection of the bronchial artery showing marked dilatation leading to sterile emboli lodged in the same lobe, and slight filling of the pulmonary artery from the bronchial artery; *b*, injection of the pulmonary artery of the isolated lobe showing the absence of filling beyond the emboli except that due to the bronchial artery. The abscess produced in the area beyond one sterile embolus, due to secondary infection from a suppurating abdominal wound, is shown in fig. 8.

Fig. 10 (animal K 49).—*a*, injection of the bronchial artery in the presence of two sterile emboli, one secondarily infected from compound fracture sustained before the introduction of jugular emboli; *b*, lobe containing abscess; *c*, cut section of lobe containing the abscess; *d*, cut section of the lobe containing the second sterile embolus without reaction about it. Note the dilatation of the bronchial artery leading to the lobes containing the emboli.

2 cm. in diameter. The second embolic area was not visible until the lung was inflated, when it was disclosed in the right lower lobe by its paler color. The branches of the bronchial artery leading to the lobes that contained the emboli were greatly dilated, and there was no filling of the pulmonary artery beyond either embolus (fig. 10).

The cut section of the left upper lobe showed an abscess cavity, 1.5 cm. in diameter, with a fairly thick wall surrounded by a limited pneumonitis. There was no pathologic change around the second embolus.

SUMMARY

1. Experimental evidence is presented indicating that infected emboli invariably produce marked pathologic changes in the parenchyma of a lung.

2. Sterile emboli, on the other hand, usually produce little gross evidence of their presence in the deflated state of the lung. When the lung is expanded by normal inflation, the sterile embolic area is paler than the surrounding lung. Clinically, pathologists would do well to examine all lungs in the normally inflated state to aid in the detection of sterile embolic areas.

3. Sterile emboli may produce hemorrhagic infarction and abscess formation due to secondary infection of the embolic area by circulating organisms.

4. Observations in the laboratory indicate that in the presence of suppurating wounds a sterile embolus lodged in the lung may produce an intrapulmonary abscess due to secondary infection of the embolic area by circulating organisms.

5. The injection of the bronchial artery by the introduction of Hill's mass shows a marked dilatation of the branches leading to the lobes containing the emboli, more marked in the lobe containing the infected embolus. This dilatation of the bronchial artery may be of considerable clinical importance in the resistance to infection and in the repair of destroyed tissue following embolic infarction and abscess formation.

6. The injection of the pulmonary artery may be normal in the presence of massive hemorrhagic consolidation which may occur without an embolus or thrombosis in the pulmonary artery. Retrograde thrombosis does not explain the hemorrhagic consolidation following the lodging of an infected embolus in a lobe.

BRONCHOGENIC CONTAMINATION IN EMBOLIC ABSCESS OF THE LUNGS*

C. M. VAN ALLEN, M.D.
NEW HAVEN, CONN.
W. E. ADAMS, M.D.
AND
L. S. HRDINA
CHICAGO

The etiology of abscess of the lung, particularly that which occurs after surgical operations, has been subject to recent clinical and experimental investigation, and much of pertinent data has been revealed. In the interpretation of this, difference of opinion has arisen as to whether inoculation of the lung occurs by aspiration of infectious material from the mouth or by embolism from an infected surgical wound. In favor of each has been presented a mass of clinical facts, and it must be admitted that most of these facts can be used equally effectively on either side of the argument. Also, experimentally, it has been possible to reproduce abscess of the lung by either portal of inoculation in substantiation. The aspiration theory has, however, been adopted by the majority as the more plausible. A critical review of the situation readily demonstrates essential defects in both explanations when applied to the etiology of typical postoperative abscess of the lung thus:

For many years pathologists have recognized that abscess of the lung may, on occasion, be produced either by septic embolism or by aspiration. A common observation after death in cases of pyemia is single or multiple acute pulmonary abscess, and the same organism is recovered from the lesion as from the primary infective focus. Also, massive aspiration of infectious material, particularly in the terminal stages of wasting diseases, is well known to give rise to bronchopneumonia, and there may be areas of softening. Here the outstanding circumstances are depleted resistance and overwhelming bacterial inoculation.

It is recognized[1] that embolism of major and minor proportions occasionally occurs following surgical operations, and the embolus is usually a fragment of blood clot loosened and deposited in the venous

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* From Department of Surgery, University of Chicago.

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1. Cutler, E. C., and Hunt, A. M.: Postoperative Pulmonary Complications, Arch. Int. Med. **29**:449 (April) 1922. Mayo, W. J.: Surg. Gynec. Obst. **32**:97, 1921. Ochsner, A. J., and Schneider, C. C.: Ann. Surg. **72**:91, 1920. Hampton, H., and Wharton, L. R.: Bull. Johns Hopkins Hosp. **31**:95, 1920. Capelle: Beitr. z. klin. Chir. **119**:485, 1920. McCann, F. J.: Brit. M. J. **1**:277, 1918. Rupp, A.: Arch. f. klin. Chir. **115**:672, 1921.

stream from a thrombus near the operative field. Moreover, thrombosis occurs most readily in the presence of infection, and these emboli may be septic. Therefore, it is altogether probable that abscess of the lung does arise, on occasion, from embolism after operation; but that this mechanism of inoculation accounts for the majority of these lesions appears doubtful. It does not explain the occurrence of abscess after sterile operations, nor does it account for the lack of correspondence between the bacterial flora typical of chronic abscess and that of the operative wound.

The strongest argument for aspiration as the mode of origin of pulmonary abscess is the close similarity between the type of bacterium infecting the lesion and that of the upper respiratory passages. Lambert and Miller [2] took cultures from ten abscesses directly at the time of pneumotomy, and found anaerobic bacteria to predominate in all. Smith [3] studied various types of chronic suppurative disease of the lung, and recovered organisms native to the oral cavity. Also, that aspiration of material from the pharynx into the bronchi takes place with great frequency is abundantly demonstrated. Daily and Daily [4] examined the tracheobronchial tree of 100 patients after tonsillectomy with general anesthesia, and found blood in seventy-eight. In a similar study, Myerson,[5] showed bacterial contamination in 76 per cent, although he had tilted the head of the table downward at an angle of 45 degrees during the operation. Iglauer [6] examined fifty patients after tonsillectomy under local anesthesia (procaine hydrochloride), and noted blood in the trachea in 38 per cent. In five of these, 5 cc. of iodized oil was given to be swallowed, and in two the oil entered the lower respiratory tract. Ochsner and Nesbit [7] found that every patient with peritonsillar infiltration anesthesia and before tonsillectomy aspirated iodized oil in trying to swallow. Corper [8] instilled india ink (2 cc.) into the nose of cónscious, unanesthetized rabbits, and discovered that a large part of it was deposited in the lung; and similar experimental results in both anesthetized and unanesthetized animals are reported by others.[9] That aspiration of pharyngeal fluids readily occurs in man without any

2. Lambert, A. V. S., and Miller, J. A.: Abscess of Lung, Arch. Surg. **8**:446, (Jan.) 1924.

3. Smith, D. T.: Am. Rev. Tuberc. **15**:352, 1927.

4. Daily, L., and Daily, R. K.: Texas State J. Med. **23**:277, 1927.

5. Myerson, M. C.: Laryngoscope **32**:929, 1922; **34**:63, 1924.

6. Iglauer, S.: Ann. Otol. Rhin. & Laryng. **37**:231, 1928.

7. Ochsner, A., and Nesbit, W.: Arch. Otolaryng. **6**:330, 1907.

8. Corper, H. J.: Pulmonary Aspiration of Particulate Matter, Normally and During Anesthesia, J. A. M. A. **78**:1858 (June 17) 1922.

9. Mullin, W. V., and Ryder, C. T.: Am. Rev. Tuberc. **4**:683, 1920. Corper, H. J., and Enright, J. J.: Eye as Portal of Infection in Respiratory Disease, J. A. M. A. **74**:521 (Feb. 21) 1920. Hoelscher, R.: Arch. f. klin. Chir. **57**:175, 1897. Lemon, W. S.: Aspiration, Arch. Surg. **12**:187 (Jan.) 1926.

form of anesthesia and unknown to the individual is known as a fact to those who are familiar with the Singer [10] method for the introduction of iodized oil intrabronchially. The patient is seated, the tongue is steadied and the oil is instilled into the pharynx. If swallowing is forbidden, the oil runs into the larynx, trachea and bronchi freely and without sensation. Myerson [11] draws the pertinent conclusion that bland substances, such as mucus, saliva, blood, etc., and others, when well mixed with mucus, do not stimulate the mucosa of the larynx and lower respiratory tract sufficiently to excite cough. Only when the mass of aspirated material is sufficient to interfere with the passage of air or when the mucosa is hyperirritable and inflamed, is the cough reflex called into play.

This fact of frequent contamination of the lower respiratory tract from the upper is, indeed, the strongest argument against the aspiration hypothesis of the origin of abscess of the lung. That lesion is rare. Moore [12] reported one abscess of the lung in 3,000 tonsillectomies; Graham [13] found no abscess in 10,000 (material from Sluder's clinic). The answer to this difficulty has been that the aspirated substance is regularly and quickly eliminated by cough, ciliary activity and bronchial peristalsis. Myerson [14] observed directly in man an evacuation time of twelve minutes, even under anesthesia and without cough! It is suggested [15] that in certain persons this mechanism of elimination fails, and from prolonged contact of the inoculum with the finer ramifications of the bronchi, infection of the parenchyma occurs. But fluid, even in small quantity and when not too viscid, introduced into the trachea, gravitates immediately to the periphery of the lung where it is beyond the expelling reach of cough and ciliary activity. Thus, Hoelscher [16] stained the buccal secretions in anesthetized dogs and found the alveoli of the lung to become stained, and Mullin and Ryder [17] noted the same condition in rabbits. Corper [8] found that particles of india ink aspirated from the pharynx reached the alveoli and remained there as long as three months. In man, after intrabronchial injection of iodized oil, it is common to see the oil reach the finest bronchioles or alveoli and remain

10. Singer, J. J.: Bronchography: Injection of Iodized Oil, Arch. Surg. **14**:167 (Jan.) 1927.

11. Myerson (footnote 5, second reference).

12. Moore, W. F.: Pulmonary Abscess, J. A. M. A. **78**:1279 (April) 1922.

13. Graham, E. A.: S. Clin. N. Amer. **2**:1501, 1922.

14. Myerson (footnote 5, first reference).

15. Hedblom, C. A.; Joannides, M., and Rosenthal, S.: Ann. Surg. **88**:823, 1928. Allen, D. S.: Etiology of Abscess of the Lung: Experimental and Clinical Studies, Arch. Surg. **16**:179 (Jan.) 1928.

16. Hoelscher (footnote 9, third reference).

17. Mullin and Ryder (footnote 9, first reference).

there for months, as shown by fluffy shadows in x-ray films. Archibald [18] found that when substances were aspirated below a certain zone in the bronchial tree, cough had the effect of driving them further toward the periphery.

The proponents of the aspiration hypothesis also assume coincidentally lowered resistance of the host. This is undoubtedly important, but difficulties arise at once. Thus, a recent autopsy at this institution demonstrated a carcinoma of the esophagus. A fistula had developed between the esophagus and the bronchus, which had permitted massive, daily bronchial contamination. The fistulous tract swarmed with fusospirochetes and other putrefying bacteria. The patient was aged and extremely cachectic. Bronchopneumonia was present but no abscess. Moreover, statistics [19] show that the lowest incidence of postoperative pulmonary complications of all sorts is seen in operations on the brain, and here the patient is frequently submitted to severest shock and hours of deep unconsciousness and depression. Indeed, the circumstances responsible for the greatest number of abscesses of the lung are quite the opposite, i.e., those of tonsillectomy, a minor operation performed on relatively young and healthy persons. If lowered resistance of the host plays an essential rôle, it is specific and not yet understood.

Animal researches in the reproduction of abscess of the lung have corroborated these conclusions, but add little. Regarding embolic inoculation, it has been shown [20] that infected emboli reaching the lung readily give rise to an abscess. If the infecting agent is one of the ordinary pus formers, as *Staphylococcus aureus,* the abscess is insignificant and heals quickly, but if more virulent and anaerobic pyogens are used, such as are native to the mouth, the abscess is usually larger and tends to become chronic.[21] On the other hand, intrabronchial inoculation has produced abscess of the lung with excessive difficulty. Lambert and Miller,[2] Aschner,[22] Cutler and Schlueter,[20] Schlueter and Weidlein,[23] and many others have insufflated or packed the bronchi with a variety of infectious materials in hundreds of animals, and produced either

18. Archibald, E., and Brown, A. L.: Am. Rev. Tuberc. **16**:111, 1927.

19. Cutler, E. C., and Hunt, A. M.: Postoperative Pulmonary Complications, Arch. Surg. **1**:114 (July) 1920.

20. Cutler, E. C., and Schlueter, S. A.: Ann. Surg. **84**:256, 1926. Holman, E.; Weidlein, I. F., and Schlueter, S. A.: Proc. Soc. Exper. Biol. & Med. **23**:266, 1926.

21. Hermann, L. G., and Cutler, E. C.: Proc. Soc. Exper. Biol. & Med. **26**:28, 1928.

22. Aschner, P. W.: Ann. Surg. **75**:321, 1922.

23. Schlueter, S. A., and Weidlein, I. F.: Postoperative Lung Abscess: Experimental Study, Arch. Surg. **14**:457 (Feb.) 1927.

bronchopneumonia, septicemia or no lesion. Similarly, Allen [24] recently failed to produce abscess of the lung, after insufflating pus from a pulmonary abscess in man into the bronchi of fifteen rats and fifteen dogs. He then modified the experiment by ligating the insufflated bronchus, in order to retain the inoculum in contact with the lung. The lesions thus obtained were termed abscesses, but they are described and illustrated as purulent, desquamative bronchitis and peribronchial leukocytic infiltration, i.e., bronchopneumonia. No protocols are published describing tissue necrosis and cavity formation, which are necessary characteristics of abscess in any part.

Intrabronchial inoculation has succeeded, however, in producing destructive lesions of the lung in animals, and here a specific organism appears to have been a constant factor, viz., the fusospirochete of Vincent. Smith [3] instilled warm, fresh suspensions of these organisms, obtained from scrapings of carious teeth in man, into the bronchi of rats, guinea-pigs and rabbits. Bronchopneumonia resulted with central necrosis, and chronic abscesses persisted in some cases for five months.[25] Crowe and Scarff, after working two years with infective agents, succeeded in obtaining abscess of the lung in nine dogs with Vincent's fusospirochetes. In eight of these, the entire lobe inoculated became gangrenous. Following them, Hedblom, Joannides and Rosenthal [26] insufflated the bronchial tree of sixty-seven dogs with a wide assortment of infectious and irritating substances. Unfortunately, little detail is given, but the inference is apparent that absceses were obtained when fusospirochetes were included in the inoculum, and these authors emphasize the importance of this group of organisms to the production of abscess. The lesion produced, as far as described, was pulmonary gangrene. In three dogs, the inoculated lobe was partially or wholly gangrenous, and in one the "abscess" measured 10 cm. in diameter, which means a widespread destruction of substance of the lung.

These experiments have, accordingly, given rise to a specific lesion, pulmonary gangrene. The work supports the original, extensive investigations of Pilot,[27] Pilot and Davis,[28] Pilot, Davis and Shapiro,[29] and Kline,[30] showing that the Vincent group of anaerobic bacteria have

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24. Allen (footnote 15, second reference).

25. Smith, D. T.: Am. Rev. Tuberc. **16**:584, 1927.

26. Hedblom; Joannides, and Rosenthal (footnote 15, first reference).

27. Pilot, I.: S. Clin. N. Amer. **9**:1433, 1926.

28. Pilot, I., and Davis, D. J.: Studies in Fusiform Bacilli and Spirochetes: Their Rôle in Pulmonary Abscess, Gangrene and Bronchiectasis, Arch. Int. Med. **34**:313 (Sept.) 1924.

29. Pilot, I.; Davis, D. J., and Shapiro, I. J.: Am. Rev. Tuberc. **8**:249, 1923.

30. Kline, B. S.: Spirochetal Pulmonary Gangrene, J. A. M. A. **77**:1874 (Dec. 10) 1921; J. Infect. Dis. **32**:481, 1923.

the capacity to necrotize and putrefy tissues; but that it furthers the question of etiology of the typical chronic abscess of the lung in man is doubtful. Pulmonary gangrene not infrequently complicates abscess of the lung, but it is in itself a distinct pathologic and bacteriologic entity. Characteristically, gangrene is acute and lacking in protective tissue reaction, while abscess may be acute or chronic and tends from the start to encapsulation. Gangrene presents a foul, penetrating odor and a bacterial flora that is putrefactive and often includes Vincent organisms; chronic abscess of the lung frequently has little odor and a mixed, largely anaerobic bacterial flora frequently including putrefying bacteria. Smith [31] studied the bacteriology of bronchopulmonary spirochetosis as reported and in cases of his own, and found included all types of suppurative disease of the lung, including abscess; following his work writers have tended to consider fusospirochetes as characteristic of abscess of the lung. Smith, however, did not demonstrate the corollary, i. e., that suppurative diseases of the lung, including abscess, are regularly due to fusospirochetes. Lambert and Miller [2] found these organisms in 30 per cent of abscesses from which cultures were taken directly. Fusospirochetes occasionally appear in lesions of the lower respiratory tract, just as they are seen at times in lesions of the tracts above the larynx. And it is as unreasonable to consider them the essential cause of abscess of the lung, as it would be to suggest that all tonsillitis, sinusitis or dental caries are caused by them, since they frequent these lesions. Nor would inoculation experiments, injecting fusospirochetes into the tonsils or sinuses of dogs and producing specific tissue putrefaction, show that tonsillitis or sinusitis occurs spontaneously from these organisms and in this manner. Surely, massive doses of such necrotizing bacteria blown into a bronchus in man would often give rise to gangrene of the lung, but these are clearly not the circumstances usually attending the onset of pulmonary abscess.

In short, both clinical and laboratory experience demonstrate the lung to be very susceptible to abscess formation from septic embolism and very resistant in this respect to bronchogenic inoculation, when bacteria are used which are common to chronic abscess of the lung. While certain abscesses of the lung in man doubtless result from embolic origin alone and others from a bronchogenic source, there remains a large group of postoperative pulmonary abscesses, which are not readily explained by either mode of origin.

For these cases we wish to suggest a combination of these two factors, where embolism contributes the initial acute abscess and aspiration changes the flora to that of the upper respiratory passages and con-

31. Smith (footnotes 3 and 25).

tributes toxicity and chronicity to the lesion. The experiments that follow are planned to test the possibility of this in animals.

EXPERIMENTAL WORK

Dogs were used, and were divided into three groups. In group 1 the effect of insufflation alone of infectious material into the bronchus was determined. In group 2 the nature of the abscess produced by embolic inoculation alone of the lung was defined. And in group 3 the change that may be effected in the character of embolic abscess of the lung as result of septic bronchial insufflation was determined.

Various types of bacteria were employed for inoculation, for the purpose of contrasting the action of a common pyogenic organism, *Staphylococcus aureus,* with that of bacteria of greater virulence, in mixture and sort as found in chronic suppurative diseases of the lung.

GROUP 1.—In this group, the effect of intrabronchial insufflation alone was determined on twenty-two dogs. The dogs were anesthetized to the extent of

TABLE 1.—*Intrabronchial Insufflation with Sputum Containing Vincent's Fusospirochetes*

Number of Dogs	Spontaneous Deaths		Killed	
	Day	Abscess	Day	Abscess
16	1	None	12	None
	1	None		None
	1	None		None
	2	None		None
	4	None		None
	4	None		None
				None
				None
				None
				None

deep sleep and loss of cough reflex for eighteen to twenty-four hours by subcutaneous injection of sodium barbital, 0.3 Gm. per kilogram of body weight. Sputum was obtained absolutely fresh, thinned with saline to lower its viscosity, and insufflated bronchoscopically into the right lower bronchus in amounts of 0.3 cc. per kilogram of body weight. Afterward, the animals were placed to sleep on the right side with the head elevated to insure retention of the inoculum in the bronchus. The subsequent behavior was noted. At death from disease or when killed after selected intervals, autopsy was done including the gross and microscopic pathologic and bacteriologic examinations of the lungs. The results of the gross pathologic examination only will be reported here as directly pertinent, and the other results will appear in subsequent publications.

Series A, sixteen dogs: Sputum containing myriads of fusospirochetes of Vincent, cocci and rods, taken from a case of bronchiectasis, was insufflated into the dogs (table 1). Six of them died in four days with pulmonary congestion, pneumonia and toxemia. Ten were killed in twelve days. Bronchitis was the only lesion found.

Series B, six dogs: Sputum containing *Fungus nocardia,* cocci and rods, obtained from a case of bronchiectatic abscess of the lung, was insufflated (table 2). Four dogs died on the second day with pulmonary congestion and toxemia. Two killed in eleven days showed bronchitis only.

GROUP 2.—In this group the effect of embolic inoculation of the lung alone was determined on fifty-four dogs.

An embolus was prepared after the method of Cutler, Holman and their associates; i. e., into the lumen of a short segment of femoral vein was placed the infectious material (fragment of cotton saturated with sputum or a piece of agar-bearing bacterial culture) and a lead bird-shot. The ends of the vein were then tied with linen thread to retain the contents. The dog to be inoculated was anesthetized with ether; an incision was made exposing the external jugular vein, and the embolus was introduced into its venous blood stream. The after-management was the same as for group 1.

TABLE 2.—*Intrabronchial Insufflation with Sputum Containing Fungus Nocardia*

Number of Dogs	Spontaneous Deaths		Killed	
	Day	Abscess	Day	Abscess
6	2	None	11	None
		None		None
		None		
		None		

TABLE 3.—*Embolic Inoculation of the Lung with Sputum Containing Fungus Nocardia*

Number of Dogs	Spontaneous Deaths		Killed	
	Day	Abscess	Day	Abscess
5		.....	30	Healed
				Large
				Large
				Large
				Large

TABLE 4.—*Embolic Inoculation of the Lung with Sputum Containing Mixed Pyogenic Organisms*

Number of Dogs	Spontaneous Deaths		Killed	
	Day	Abscess	Day	Abscess
6	6	Gangrene	63	Large
				Large
				Large
				Large
				Very large

Series A, five dogs: An embolus infected with sputum containing *Fungus nocardia,* cocci and rods, obtained from a case of bronchiectatic abscess of the lung (group 1, B), was introduced (table 3). All dogs were killed in thirty days. One showed the lead pellet encapsulated in fibrous tissue in the parenchyma of the lung and no abscess. Four presented a large abscess at the site of the embolus. The walls of the abscess were soft, and the cavity contained purulent material and the remains of the embolus. The surrounding lung was more or less consolidated with active inflammatory reaction. The bronchi contained mucopurulent secretion and were injected.

Series B, six dogs: An embolus infected with sputum containing mixed pyogenic cocci and rods and without specific bacteria, obtained from a case of postpneumonic abscess of the lung, was introduced (table 4). One dog died on

the sixth day with extensive gangrene of the left upper lobe of the lung, lying in a pyramidal area distal to a small abscess containing the embolus. Both pleural cavities contained purulent fluid. Five dogs were killed in sixty-three days, and all showed a large abscess at the embolus. These differed on the whole from those in series A in that their walls were more fibrous, less débris was in the cavities and the surrounding parenchyma was less inflamed.

Series C, twenty-six dogs: An embolus infected with sputum containing a mixture of pyogenic cocci and rods and without specific bacteria, obtained from a case of bronchiectasis, was introduced (table 5). Twelve dogs died; six of these died in six days with pulmonary congestion, pneumonia and general toxemia; and six in from nine to seventeen days, three with distemper and three from the effects of a large acute abscess of the lung at the embolic focus. Eight were killed in sixty-four days. Seven showed the embolus encapsulated in scarred parenchyma of the lung, and one had a large abscess similar to those described in the previous series. One was killed in ninety-one days and presented a large chronic abscess of the lung (fig. 1). Five were killed in 119 days. In one there

TABLE 5.—*Embolic Inoculation of the Lung with Sputum Containing Mixed Pyogenic Organisms*

Number of Dogs	Spontaneous Deaths		Killed					
	Day	Abscess	Day	Abscess	Day	Abscess	Day	Abscess
26	2	None	64	Healed	91	Large	119	None
	5	None		Healed				Healed
	8	None		Healed				Healed
	5	None		Healed				Large
	6	None		Healed				Large
	6	None		Healed				
	9	Large		Healed				
	9	Large		Large				
	10	None						
	13	Large						
	15	None						
	17	None						

had apparently been no abscess, for the embolus was contained in intact arterial walls; in two the abscess was healed, for the embolus was embedded in scar; and in two there was a large abscess. This was represented by a cavity with fibrous walls, no contents, a smooth surface and without surrounding pneumonitis (fig. 2).

Series D, seventeen dogs: An embolus infected with blood agar culture of *Staphylococcus aureus,* of known virulence in man, twenty-four hours old, was introduced (table 6). Three dogs died of distemper in from fourteen to twenty-two days; two of these had an healed abscess and the other had a very small abscess cavity a trifle larger than the bird-shot it contained. Fourteen were killed in thirty days. In two there was a small abscess of the lung nearly healed, and in the others evidence of healed abscess was found, or no inflammatory reaction at all at the site of the embolus.

GROUP 3.—In this group the effect of embolic inoculation of the lung, plus intrabronchial inoculation, was determined on sixty-eight dogs.

Pulmonary embolism was induced, as in group 2, and on the tenth day the position of the embolus in the lung was localized by the x-rays, and the bronchus to that part was inoculated, as in group 1. In each case, the embolus carried *Staphylococcus aureus* (group 2, D). For insufflation, sputum was used from the cases in the foregoing experiments, also *Staphylococcus aureus* alone and sterilized sputum alone.

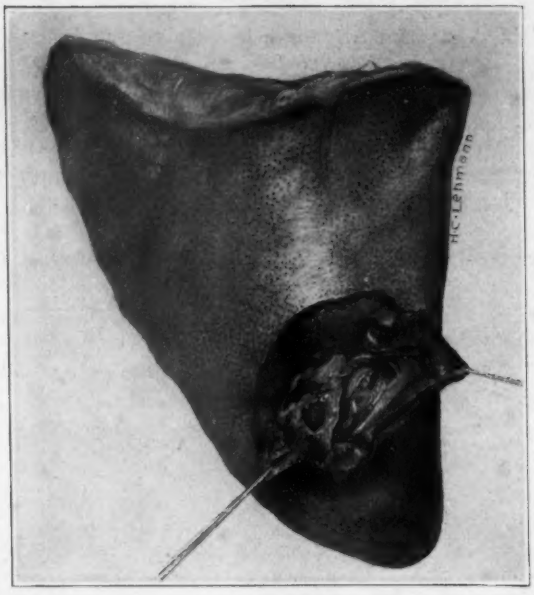

Fig. 1.—Right lower lobe of the lung, incised to show abscess ninety-one days after embolic inoculation with sputum containing a mixture of pyogenic cocci and rods (no specific bacteria). See group 2, series C.

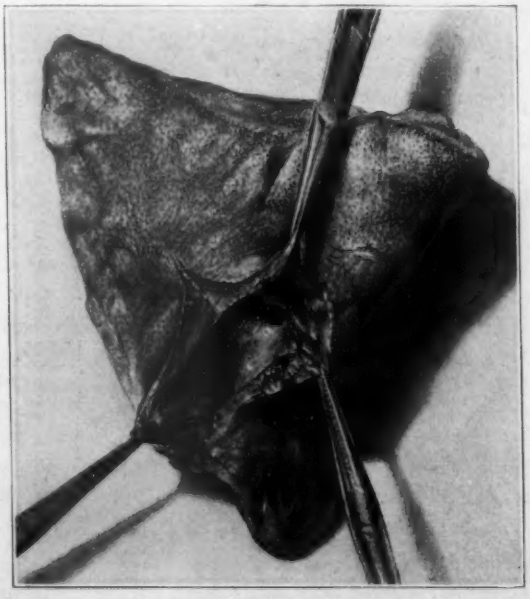

Fig. 2.—Right lower lobe of the lung, incised to show abscess 119 days after embolic inoculation with sputum containing a mixture of pyogenic cocci and rods (no specific bacteria). See group 2, series C.

Series A, eight dogs: An embolus infected with *Staphylococcus aureus* was introduced, and sputum containing fusospirochetes of Vincent, cocci and rods, obtained from a case of bronchiectasis (group 1, A), was insufflated (table 7). Two dogs died in twelve days from the effects of large acute abscess and the toxemia of insufflation (fig. 3). Six dogs were killed in thirty-four days, and all showed a large abscess at the embolic site. This contained pus and débris, and the surrounding lung was consolidated.

TABLE 6.—*Embolic Inoculation of the Lung with Agar Culture of Staphylococcus Aureus*

Number of Dogs	Spontaneous Deaths		Killed	
	Day	Abscess	Day	Abscess
17	14	Small	30	None
	21	Healed		None
	22	Healed		None
				Healed
				Healed
				Healed
				Healed
				Healed
				Healed
				Healed
				Healed
				Healed
				Small
				Small

TABLE 7.—*Embolic Inoculation of the Lung with Staphylococcus Aureus Plus Intrabronchial Insufflation with Sputum Containing Vincent's Fusospirochetes*

Number of Dogs	Spontaneous Deaths		Killed	
	Day	Abscess	Day	Abscess
8	12	Large	34	Large
		Large		Large
				Large
				Large
				Large
				Large

TABLE 8.—*Embolic Inoculation of the Lung with Staphylococcus Aureus Plus Intrabronchial Insufflation with Sputum Containing Fungus Nocardia*

Number of Dogs	Spontaneous Deaths		Killed	
	Day	Abscess	Day	Abscess
6	1	None	30	Healed
	11	Small		Healed
	11	Small		Large

Series B, six dogs: An embolus infected with *Staphylococcus aureus* was introduced, and sputum, containing *Fungus nocardia,* cocci and rods, obtained from a case of bronchiectatic abscess of the lung (group 1, B and group 2, A) was insufflated (table 8). Three dogs died; one of these died after twenty-four hours from unknown causes, and two died in eleven days as the result of the toxemia of insufflation. Each of the latter presented small acute abscess of the lung. Three dogs were killed in thirty days; two of these had an healed abscess, and one had a large acute abscess containing the embolus.

Series C, eighteen dogs: An embolus infected with *Staphylococcus aureus* was introduced, and sputum containing mixed pyogenic cocci and rods and no specific bacteria, obtained from a case of bronchiectasis (group 2, C), was insufflated (table 9). Six dogs died in from three to ten days; four with pulmonary congestion and toxemia, and two with distemper. Three showed a small abscess at the site of embolism. Five were killed in sixty-two days. Of these, three had an healed abscess, one a small, active abscess, and one a very large, chronic abscess. Seven were killed in ninety-three days. Five had an healed abscess and two a large abscess. One of the latter abscesses was of the indolent type with

TABLE 9.—*Embolic Inoculation of the Lung with Staphylococcus Aureus Plus Intrabronchial Insufflation with Sputum Containing Mixed Pyogenic Organisms*

Number of Dogs	Spontaneous Deaths		Killed			
	Day	Abscess	Day	Abscess	Day	Abscess
18	3	None	62	Healed	93	Healed
	3	None		Healed		Healed
	6	None		Healed		Healed
	8	Small		Small		Healed
	10	Small		Large		Healed
	10	Small				Large
						Large

TABLE 10.—*Embolic Inoculation of the Lung with Staphylococcus Aureus Plus Intrabronchial Insufflation with Staphylococcus Aureus*

Number of Dogs	Spontaneous Deaths		Killed			
	Day	Abscess	Day	Abscess	Day	Abscess
27	1	None	30	Healed	61	None
	2	None		Healed		None
	2	None		Healed		Healed
	2	None		Small		Healed
	3	Small		Large		Healed
	4	Large				Small
	7	None				Small
	8	None				Small
	9	Small				
	9	Large				
	11	None				
	11	None				
	12	None				
	28	Healed				

little remaining inflammation (fig. 4). The other had a multilocular cavity, filled with thick pus, and the adjacent lung was widely consolidated.

Series D, twenty-seven dogs: An embolus infected with *Staphylococcus aureus* was introduced, and *Staphylococcus aureus* in twenty-four hour broth culture was insufflated (table 10). Fourteen dogs died within twenty-eight days from an epidemic of distemper that decimated the stock at this time. Four of these had an embolic abscess, two small, one medium and one large. Five dogs were killed in thirty days; three had an healed abscess, one a very small, inactive abscess, and one a large abscess filled with purulent material. Eight were killed in sixty-one days, and three of these showed a small, nearly healed abscess at the embolic site.

Series E, nine dogs: An embolus infected with *Staphylococcus aureus* was introduced, and sterilized sputum was insufflated (table 11). Three dogs died in seven days, with pulmonary congestion and toxemia. No abscesses were found

Fig. 3.—Left lower lobe of the lung showing abscess twelve days after embolic inoculation with *Staphylococcus aureus* and two days after intrabronchial insufflation with sputum containing fusospirochetes of Vincent. See group 3, series A.

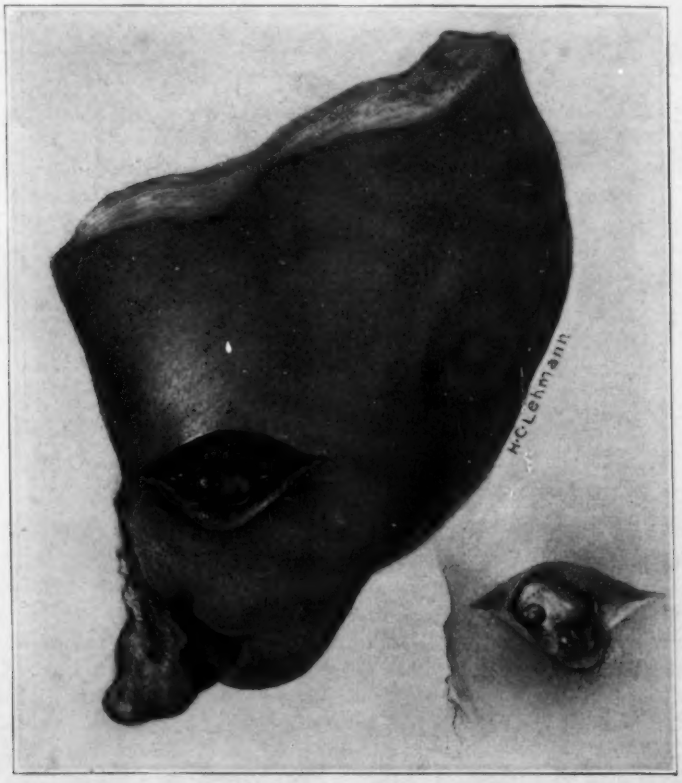

Fig. 4.—Left lower lobe of the lung showing abscess ninety-three days after embolic inoculation with *Staphylococcus aureus* and eighty-three days after intrabronchial insufflation with sputum containing mixed pyogenic cocci and rods (no specific bacteria). See group 3, series C.

and the emboli were contained in intact arterial walls. Six were killed in thirty-one days. In five there was evidence of healed abscess, and in one apparently no abscess had existed.

Summary of Results.—The experiments include 144 dogs, divided into three groups (table 12).

Group 1, twenty-two dogs, received only intrabronchial insufflation of sputum from cases of chronic suppurative pulmonary disease. The mortality, 45 per cent, was from pneumonia, empyema and toxemia. No abscess of the lung developed.

TABLE 11.—*Embolic Inoculation of the Lung with Staphylococcus Aureus Plus Intrabronchial Insufflation with Sterile Sputum*

Number of Dogs	Spontaneous Deaths		Killed	
	Day	Abscess	Day	Abscess
9	1	None	31	None
	4	None		Healed
	7	None		Healed
				Healed
				Healed
				Healed

TABLE 12.—*Summary*

Group	Method of Inoculation	Inoculum	Number of Dogs	Per Cent Survived	Per Cent With Abscess Active			
					1 Mo.	2 Mo.	3 Mo.	4 Mo.
1	Insufflation	Sputum	22	55	0			
2	Production of embolism	(1) Sputum	37	65	54	47	50	40
		(2) Staphylococcus aureus	17	82	14			
3	Production of embolism plus insufflation	Staphylococcus aureus						
		(1) Sputum	32	66	52	33	29	
		(2) Staphylococcus aureus	27	45	39	37		
		(3) Sterile sputum	9	66	0			

Group 2, fifty-four dogs, received only infected emboli. In a part of these the embolus was infected by sputum, and in the remainder by *Staphylococcus aureus* culture. The mortality was 29 per cent. Of those inoculated with sputum and surviving, 54 per cent had abscess of the lung unhealed at one month, 47 per cent unhealed at two months, 50 per cent unhealed at three months, and 40 per cent at four months. Of those inoculated with *Staphylococcus aureus* and surviving, 14 per cent had abscess of the lung at one month, and these were small and nearly healed.

Group 3, sixty-eight dogs, received embolic inoculation of the lung with *Staphylococcus aureus* and, ten days later, intrabronchial insufflation of various inocula. The mortality was 41 per cent. In a part of the dogs, sputum was insufflated, and of the survivors, 52 per cent had an

abscess of the lung unhealed at one month, 33 per cent unhealed at two months, and 29 per cent unhealed at three months. In a second part, *Staphylococcus aureus* culture was insufflated, and of those surviving, 39 per cent had unhealed abscess at one month and 37 per cent at two months. In a third part, sterilized sputum was insufflated and no abscess remained to one month.

COMMENT AND CONCLUSIONS

The first two groups of experiments determine the mode of reaction of the lung separately to embolic and bronchogenic inoculation, and serve as controls for the third group. Two phenomena are illustrated thereby that we have already referred to from the work of others, but which deserve emphasis.

Thus, first, the lung is far more susceptible to abscess formation from embolic than from bronchogenic inoculation. This is of importance in the question of etiology of abscess of the lung, and further study has been made of its nature and causes.[32]

Second, these experiments demonstrate a direct relation between the type of organism infecting an embolic abscess of the lung and the virulence and chronicity of the abscess. Accordingly, *Staphylococcus aureus* alone produced small abscesses which tended to heal in a few weeks, while mixtures of pyogenic bacteria, such as exist in the sputum of chronic suppurative pulmonary diseases (nontuberculous), evolved large abscesses that often required months for healing. We disagree with recent authors who claim a specificity of fusospirochetes of Vincent for the production of chronic abscess of the lung. Experimentally, at least, the common pyogenic cocci and rods of sputum are as capable of inducing abscesses slow to heal as are spirochetes.[33]

Group 3 indicates the effect that intrabronchial contamination may have on the character of a preexisting abscess of the lung. Here the abscess was initiated by an embolus carrying a type of bacterium (*Staphylococcus aureus*) that produces essentially insignificant and rapidly healing abscesses. Insufflation of sputum organisms was carried out on the tenth day. The virulence and chronicity of the abscess were found to be enhanced to a degree similar to that characteristic of abscess of the lung initiated by sputum organisms. Secondary contamination of the abscess by way of the bronchi is believed to play an important rôle in production of this alteration.

We suggest a circumstance, as here, with initiation of the abscess by infected embolus and propagation by bronchogenic contamination, as

32. Van Allen, C. M.; Adams, W. E., and Hrdina, L. S.: Embolism in Bronchogenic Infection of the Lung, p. 1279 of this issue.

33. Van Allen, C. M.; Adams, W. E., and Hrdina, L. S., ready for publication.

pertaining to the pathogenesis of certain postoperative chronic abscesses of the lung in man, which we have referred to in the introduction as inadequately explained by supposing either mode of inoculation to act alone. This would account, in the embolic theory, for the disparity often existing between the bacterial flora of the abscess and that of the operative field; and, again, why abscess of the lung regularly contains organisms native to the mouth, in spite of the excessive difficulty with which these organisms, when introduced into the bronchus, produce abscess of the lung. Thus, the main obstacle of each hypothesis taken alone is removed by combining the two. This mode of origin corresponds, also, with the rarity of abscess of the lung as a postoperative complication, since postoperative embolism is unusual; only certain of the emboli carry organisms capable of forming abscess, and of the abscesses a part only would be expected to acquire communication with a bronchus to permit contamination.

In one series of dogs (group 3, D), a moderate but distinct increase in virulence and chronicity of *Staphylococcus aureus* abscess followed intrabronchial insufflation of the same organism. Other experiments are under way, in which the same organism is employed for insufflation as for embolism, and these show the same effect. Evidently, replenishment of the bacterial flora in the abscess can maintain it, as well as can alteration of the bacterial flora types. This probably explains reactivation of bronchiectasis that occurs during recrudescences of chronic paranasal sinusitis.[34] Superinoculation by aspiration accounts for the fact that postpneumonic abscess of the lung also is commonly infected with bacteria from the mouth.[3]

It has been pointed out in objection to the embolic origin of postoperative abscess of the lung that in many cases signs and symptoms of pulmonary embolism do not appear in the prodromal period. This is true, but one needs only to recall how frequent it is to see at autopsy small pulmonary infarcts, even acute embolic abscesses of the lung which have gone undiagnosed in the wards, to appreciate that minor embolism may occur without recognizable signs during life.

The theory of combined origin of postoperative abscess of the lung, as outlined here, fails to account for those abscesses which occur after a sterile operation. The explanation of this on a similar basis is considered in another communication.[32]

SUMMARY

Attention was called to the fact that a large group of postoperative abscesses of the lung exists which is not adequately explained as to etiology either by embolic or by bronchogenic inoculation, acting alone.

34. Graham, E. A., in discussion on Lemon, W. S.: Aspiration, Arch. Surg. **12**:187 (Jan.) 1926.

The effect of a combination of these two avenues of inoculation of the lung was tested experimentally.

It was found that embolic abscesses of the lung could be enhanced in virulence and chronicity by insufflation of infectious material into the bronchus. This combination of embolic and bronchogenic inoculation may explain the pathogenesis of the obscure group of postoperative abscesses of the lung. Superinoculation by aspiration of pharyngeal secretions may be responsible chiefly for the maintenance of chronic abscess of the lung, both postoperative and postpneumonic, and for recrudescences in bronchiectasis.

EMBOLISM IN BRONCHOGENIC INFECTION OF THE LUNG*

C. M. VAN ALLEN, M.D.
NEW HAVEN, CONN.

W. E. ADAMS, M.D.
AND
L. S. HRDINA
CHICAGO

In another publication [1] are described the effects on the lung of dogs produced by embolic and intrabronchial inoculation, employed separately and combined. It appeared that interaction of both of these portals of entry for organisms to the lung pertains to the pathogenesis of certain postoperative abscesses of the lung in man of obscure origin.

These experiments, moreover, emphasized the fact that abscess develops readily from embolic inoculation of the parenchyma of the lung, but with great difficulty, if at all, after intrabronchial implantation of the same infecting agents, although used in enormously larger quantity. This phenomenon is considered further in the present communication.

Others have called attention to the same circumstance. One explanation has been that embolism interferes with the blood supply of the part inoculated and lowers its resistance.[2] Another reason, more generally given,[3] is that material deposited in the tracheobronchial tract is quickly removed by cough and ciliary activity, and invasion of the parenchyma is thus prevented. But the latter fails to consider the abundant clinical and experimental proof available that fluids, even in small amounts, deposited in the trachea gravitate readily to the terminal ramifications of the bronchial tree and tend to remain there beyond the reach of natural expelling forces.

The resistance of the lung to abscess formation from intrabronchial contamination is not due to failure of inoculation. It is well appreciated,[4]

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* From the Department of Surgery, University of Chicago.

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1. Van Allen, C. M.; Adams, W. E., and Hrdina, L. S.: Bronchogenic Contamination in Embolic Abscess of the Lung, p. 1262 of this issue.

2. Cutler, E. C., and Schlueter, S. A.: Ann. Surg. **84**:256, 1926.

3. Myerson, M. C.: Laryngoscope **32**:929, 1922. Hedblom, C. A.; Joannides, M., and Rosenthal, S.: Ann. Surg. **88**:823, 1928. Allen, D. S.: Etiology of Abscess of the Lung: Experimental and Clinical Studies, Arch. Surg. **16**:179 (Jan.) 1928.

4. Christie, R. V.; Ehrich, W., and Binger, C. A. L.: J. Exper. Med. **47**: 741, 1928.

since the work of Meltzer and his associates,[5] that inoculation of the bronchi with various types of pyogenic organisms frequently produces pneumonia. In man, also, aspiration pneumonia is a definite clinical entity. In pneumonia, the parenchyma of the lung is invaded by bacteria and heavily infiltrated by polymorphonuclear leukocytes to the extent that the cut surface of a specimen drips with pus, and yet the tissue vitality is regularly maintained; if the individual survives, resolution takes place speedily and without persisting cellular alterations. Another tissue thus heavily infected regularly breaks down and develops abscess. This difference between the lung and other tissues must be explained by assuming for the lung a much greater vitality in the presence of infection.

It may well be that this greater vitality is related to the matter of blood supply, for the lung receives a much greater volume of blood in proportion than does any other organ or tissue. In addition to the supply from the bronchial arteries, which is comparable to that alone enjoyed by most other tissues, the lung receives through its capillaries from the pulmonary artery the entire mass of circulating blood at each cycle. But to say that reduction of this blood supply by embolic occlusion of the pulmonary artery devitalizes the tissues lacks demonstration. Karsner and Ash [6] and Krampf [7] showed that bland embolism produces relative ischemia of the sector of lung involved and that this persists but does not produce tissue alterations. The bronchial circulation is sufficient to maintain the life of the parenchyma, and only when additional vascular injury is instituted, do changes occur interpretable as phenomena of devitalization.

The object of the experiments to be presented is to test the validity of the following hypothesis:

The greater vitality of the lung in infections is due mainly to a greater blood supply, and elimination of the pulmonary circulation reduces the blood supply and tissue vitality to the common level.

For this purpose, the reaction of the normal lung to intrabronchial contamination is compared to that of the lung which is the seat of bland embolism and is, therefore, nourished only by the bronchial circulation.

EXPERIMENTAL WORK

The experiments were divided into three groups. Dogs were used throughout.

The purpose of the first group was to determine the effect of a sterile embolus of small size on the parenchyma of the lung; that of the second to determine the results of intrabronchial insufflation of infectious material; and that of the third the reaction of the lung to a combination of bland embolism and septic insufflation.

5. Wollstein, Martha; and Meltzer, S. J.: J. Exper. Med. **16**:126, 1912. Lamar, R. V., and Meltzer, S. J.: J. Exper. Med. **15**:133, 1912.

6. Karsner, H. T., and Ash, J. E.: J. M. Research **27**:205, 1912.

7. Krampf, F.: Deutsche Ztschr. f. Chir. **189**:216, 1924.

The embolus used was a small, lead bird-shot. This could be localized in the tissues by roentgen examination. The embolus was introduced into the external jugular vein through a small incision. The inoculum for intrabronchial insufflation was sputum obtained freshly from patients with chronic suppurative pulmonary diseases. The sputum was thinned with saline to reduce its viscosity, and 0.3 cc. per kilogram of body weight was injected bronchoscopically into the right lower bronchus or, in the embolized dogs, into the bronchus which supplied the embolized lobe of the lung. Introduction of an embolus and septic insufflation were utilized at the same sitting in the third group of experiments.

Local anesthesia (procaine hydrochloride, 0.5 per cent) with morphine was used for operation in group 1, in order not to risk bronchial contamination which might take place by aspiration under general anesthesia. The other animals were anesthetized by subcutaneous injection of sodium barbital, 0.3 Gm. per kilogram of body weight, and morphine. This induced deep sleep and inhibition of the cough reflex for from eighteen to twenty-four hours.

The behavior of all dogs was carefully noted. When they died from disease or were killed within fourteen days, postmortem examination was made with special reference to the gross and histologic appearance of the lungs.

In presentation, the material will be grouped and illustrated by characteristic protocols in brief.

GROUP 1.—In this group the effect of a sterile embolus alone was determined on six dogs. Five of them were killed on the eighth day, apparently in normal physical condition. At autopsy, four presented no gross or histologic evidence of alteration in the parenchyma of the lung at the embolus or elsewhere. The fifth showed a single spot of hemorrhagic infiltration lying in the lung margin distal to the embolus. In another lobe was a patch of resolving pneumonia typical of distemper, and the bronchi were injected and contained mucus.

The sixth dog died on the seventh day with symptoms of acute respiratory infection. The lungs contained extensive areas of pneumonic consolidation. The bronchi were filled with pus. In the right upper lobe was a sharply demarcated pyramidal area of gangrene, with the embolus situated at its apex near the hilum. The pleural cavity held 200 cc. of bloody fluid.

GROUP 2.—In this group the effects of intrabronchial insufflation alone was determined on twenty-two dogs. For six dogs, sputum was used from a case of bronchiectatic abscess of the lung and contained *Fungus nocardia,* cocci and rods. For the remainder, sputum was employed from a patient with bronchiectasis and contained fusospirochetes of Vincent, with cocci and rods. The observations in the two series were similar.

Ten dogs died in from one to four days with symptoms of respiratory infection; at autopsy they showed purulent bronchitis, edema and congestion of the lungs and, in some instances, bronchopneumonia. Thus:

Protocol (dog 7).—After recovery from the anesthetic, the animal remained quiet and refused food. On the third day, it became weaker and began to cough. Mucopus dripped from the nostrils. Dyspnea developed the following day, and the dog died. Autopsy showed the pleural cavities about one third filled with purulent fluid. The bronchi contained frothy pus, and the lungs presented several patches of bronchopneumonic consolidation. These areas showed no softening or abscess formation. Histologically, the parenchyma was massively infiltrated with polymorphonuclear leukocytes, and the vitality of the tissues was preserved at all points.

The remaining twelve dogs survived and were killed twelve days after insufflation. Seven presented normal lungs, three had purulent bronchitis, and two multiple areas of bronchopneumonia. The consolidated parts were firm and infiltrated with pus, but without abscess formation or other sign of loss of tissue vitality.

Group 3.—In this group the effect of a sterile embolism plus intrabronchial insufflation was determined on thirty-six dogs.

For ten dogs, sputum was used from a case of bronchiectasis containing nonspecific pyogenic cocci and rods. For the others, the sputum was the same as for the second series of group 2 and contained Vincent's fusospirochetes, cocci and rods.

The effects in both series were similar. Seven dogs died in two days with purulent bronchitis and pulmonary edema and congestion. Three of these showed no alteration whatsoever in the embolized part of the lung, and four presented hemorrhagic infarct-like areas. Thus:

Protocol (dog 12).—Death occurred on the second day, preceded by symptoms of acute respiratory disease. On examination, the bronchi were found injected and containing mucopus. The lungs were heavy and red but air-containing, and on section dripped thin bloody fluid. The embolus was situated at the center of the left lower lobe in the lumen of an arteriole, and the lung substance peripheral to this point, in a pyramidal area, was infiltrated with blood and firmer in consistency than the surrounding lung, although air-containing. Figure 1 gives the microscopic appearance of this tissue. The alveolar septums are seen to be packed with extravasated red blood corpuslces.

Four dogs died in from four to seven days with purulent bronchitis, bronchopneumonia and hemorrhagic infarction of the lung. The pneumonic areas were similar to those in group 2 (dog 7), and the infarcts the same as that in dog 12 of this group.

Twenty-five dogs survived and were killed on the twelfth day. These may be classified according to the type of lesion presented, as follows:

Thirteen had purulent bronchitis of various degrees of severity, and the embolized parts of the lungs presented hemorrhagic infarct formation. These infarcts differed little from that of dog 12.

Four showed bronchitis, bronchopneumonia and hemorrhagic infarct.

Five had bronchopneumonia, and the embolized zone presented atelectasis. Thus:

Protocol (dog 32).—During the first seven days after inoculation, the animal appeared sick, refused food and lost weight markedly. There were no respiratory symptoms. At autopsy on the twelfth day, the bronchi were found to hold a moderate amount of mucopus and the parenchyma to have firm, elevated, airless gray patches, infiltrated with pus but intact and without abscess formation. The embolus was found in the center of the right middle lobe, and the surface of the lung distal to this was depressed, smooth, dark gray and airless. Section showed this solid tissue to extend into the parenchyma from 2 to 3 mm. from the surface only, and the tissues beneath were more fibrous than normal, but air-containing. No evidence of active inflammation was present. On blowing into the bronchus of the lobe to inflate the lung, the solid area did not fill with air. This lesion is illustrated in figure 2 in specimens from three of the dogs.

Two showed bronchitis, bronchopneumonia and septic infarction. Thus:

Protocol (dog 17).—Depression, anorexia, increasing weakness, and finally cough and nasal discharge followed the inoculation. Extreme dyspnea preceded death in twelve days. At autopsy, the lungs showed multiple areas of consolida-

tion, swollen, gray and exuding pus on section. The histologic appearance of these areas was that typical of bronchopneumonia, as in dog 7, and without loss of tissue vitality (fig. 3). The embolus was lodged in the left upper lobe near the hilum (fig. 4). Distal to this point was a sharply demarcated area of infarct distribution that was consolidated but presented a different appearance from that of the consolidated patches elsewhere. The surface was covered with fibrin and adherent to the parietal pleura. At several points the surface was ulcerated and, on being detached from the wall of the chest, exuded pus. The consistency of the underlying lung was soft. On section, it was uniformly gray and the tissue

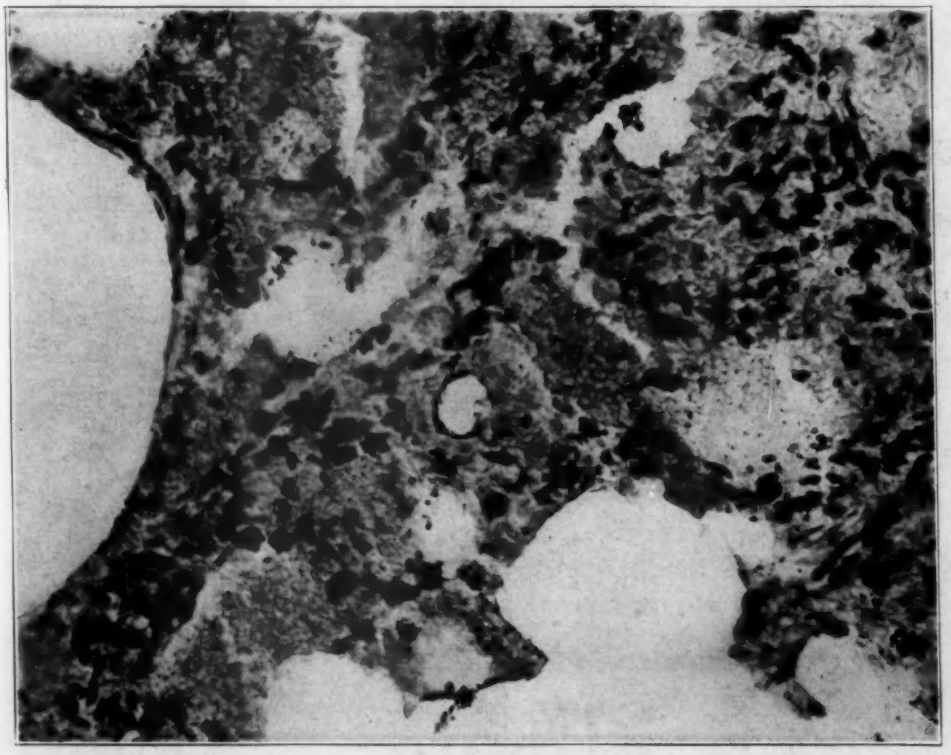

Fig. 1 (dog 12).—Photomicrograph of the infarcted area of the lung two days after bland embolism and septic intrabronchial insufflation. Note the extravasation of the red blood corpuscles in the alveolar walls.

at points liquefied and degenerated into abscesses containing thick pus and débris. At other parts, and particularly in the region of the interlobular septums, the parenchyma appeared viable although heavily infiltrated with purulent exudate. Histologically, the lung in this sector was found largely gangrenous and infiltrated with polymorphonuclear leukocytes (fig. 5). The bronchioles and the connective tissues immediately surrounding them were intact, but also infiltrated.

A similar picture of septic infarction with focal necrosis was shown by the other dog and is illustrated in figure 6.

Dog 14 presented purulent bronchitis, bronchopneumonia and abscess.

Protocol (dog 14).—The dog was acutely ill after insufflation and until it was killed in twelve days. The trachea and bronchi contained considerable mucopus. While there was a general pulmonary congestion, the only significant lesion found was in the left upper lobe (fig. 7). The distal surface of the lobe was firmly attached to the parietal pleura and the distal half of the lobe was occupied by a single abscess cavity filled with foul smelling pus. Immediately adjacent to the abscess on its proximal side and embedded in a vessel lumen in relatively normal parenchyma of the lung was found the embolus.

Dog 25 had bronchitis, bronchopneumonia and gangrenous infarction.

Protocol (dog 25).—When killed on the twelfth day, the dog was severely ill and had been progressively so for many days, with cough, loss of appetite and failing weight and strength. Autopsy showed the lungs partly collapsed by an

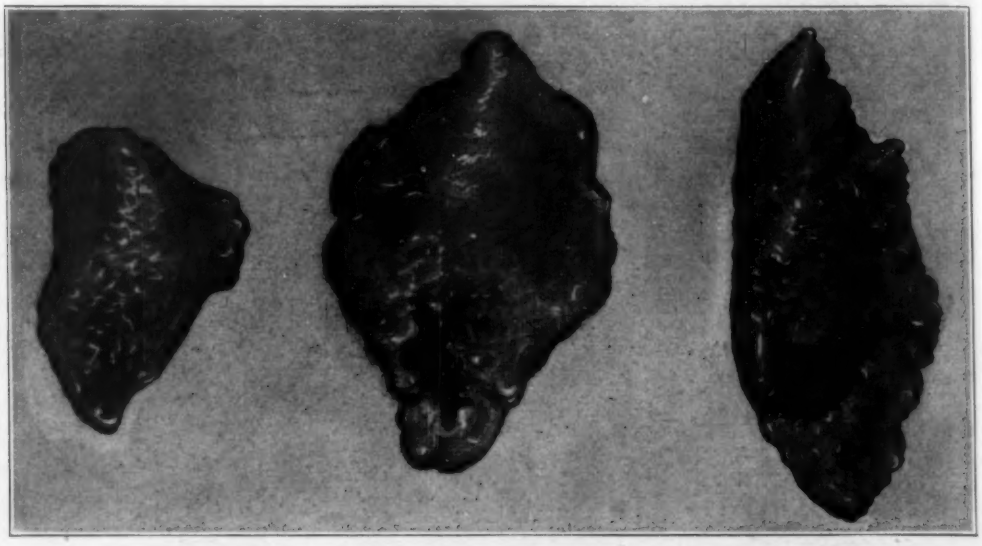

Fig. 2.—Lobes of three dogs twelve days after bland embolism and septic intrabronchial insufflation. The embolized sector presents a patch of superficial chronic atelectasis.

accumulation of thin, purulent, foul fluid in the pleural cavities. There was an intense purulent bronchitis and general pulmonary congestion and edema. The left upper lobe (fig. 8) was attached to the parietal pleura with fibrin strands that separated easily. The lobe was sharply divided into two nearly equal parts, one air-containing and similar in appearance to the other lobes, and the other airless, soft and black. On section, the latter portion was uniformly black, soft and friable, and the embolus was found just proximal to it. Microscopically, the infarcted tissue was totally and uniformly necrotic.

Summary of Results.—Sixty-four dogs comprised three groups of experiments. In six dogs, sterile embolus was given alone. One died of pneumonia on the seventh day and showed a gangrenous infarct of

the lung. The remaining dogs were killed on the eighth day. One had a small area of hemorrhagic infiltration in the embolized zone and a bronchopneumonic infiltration elsewhere. The other four were free from pulmonary infection and showed absolutely no change in the embolized portion of lung.

Twenty-two dogs were inoculated intrabronchially with sputum from patients with chronic suppurative diseases of the lungs. Ten of these died within four days from toxemia and showed bronchitis, pulmonary congestion and pneumonia. Twelve survived, and on the twelfth day two showed bronchopneumonia, three purulent bronchitis, and seven had normal lungs. In none of this group was there pulmonary abscess

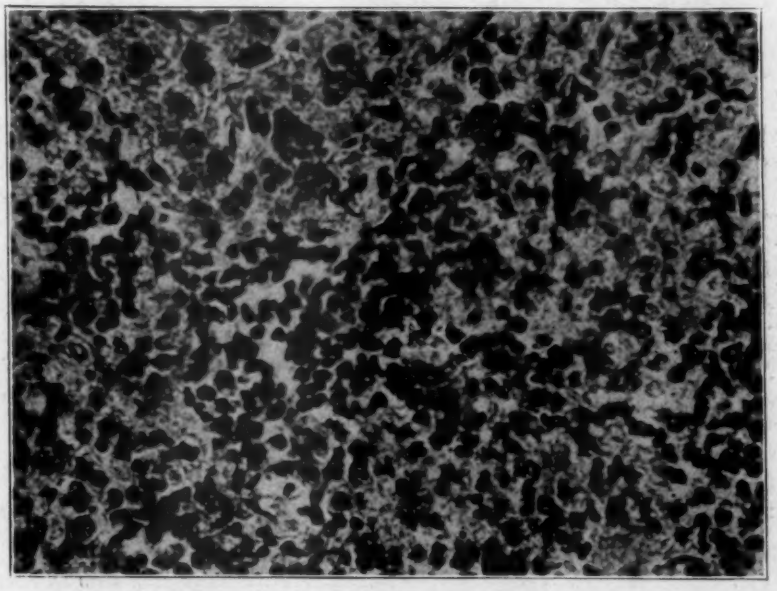

Fig. 3 (dog 17).—Photomicrograph of the lung with insufflation pneumonia at twelve days. Note the retention of tissue vitality.

formation or other evidence of devitalization of the parenchyma of the lung.

Thirty-six dogs received both sterile embolus and intrabronchial sputum inoculation. Seven died in two days from toxemia and showed bronchitis and pulmonary congestion. The embolized portion of the lung was hemorrhagic in four and unchanged in three. Four other dogs died in from four to seven days, with bronchitis, bronchopneumonia and hemorrhagic infarction. The remaining twenty-five survived until killed in twelve days; autopsy showed a variety of lesions in the embolized segment of the lung. Thus, seventeen dogs had hemorrhagic infarcts, five atelectasis of a chronic type, two inflammatory consolidation with

focal necrosis, one solitary abscess formation, and one frank massive gangrene.

COMMENT AND CONCLUSIONS

These experiments demonstrate different effects following intrabronchial inoculation of lung that has been embolized from those which occur after such inoculation of normal lung or from the embolus acting alone.

Where bland embolism was employed alone, no cellular alterations appeared in the segment of lung affected, in four of six dogs so treated. It is significant that in the remaining two animals, where changes did occur, viz., hemorrhagic infarction and gangrenous infarction, other

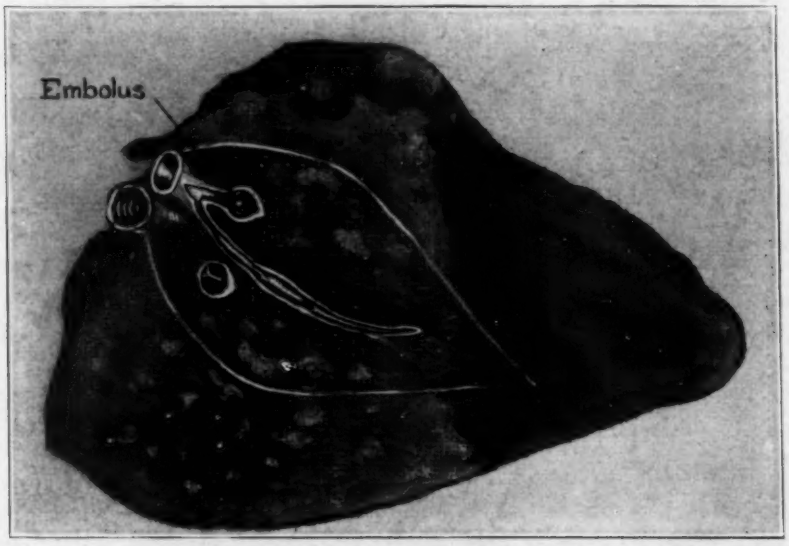

Fig. 4 (dog 17).—Left upper lobe twelve days after bland embolism and septic intrabronchial insufflation. The infarcted zone presents foci of necrosis, some of which extend to the pleural surface.

parts of the lungs displayed evidences of infection acquired spontaneously. The infarct lesions were similar to those appearing in group 3 in which the lung was intentionally infected. Accordingly, this group alone suggests that bland embolism affects no cellular alterations unless the lung is infected.

Intrabronchial inoculation of the normal lung resulted in a high mortality from toxemia and pneumonia. Several animals, on the other hand, were not made appreciably ill and in twelve days showed no lesions other than bronchitis. Others developed pneumonia and were recovering when killed. In none of these twenty-two dogs was there devitalization of the lung and abscess formation, although every opportunity was

afforded for inducing suppuration by using highly virulent and specific bacteria (Vincent's fusospirochetes and *Fungus nocardia*) in mixtures with other pyogenic organisms from a focus of pulmonary suppuration and by depressing cough reflexes and retaining the inoculum in contact with the lung for many hours after inoculation.

Intrabronchial inoculation combined with bland embolism resulted in hemorrhagic infarction in twenty-five of the thirty-six dogs so treated. Five showed chronic atelectasis, two inflammatory consolidation with focal necrosis, one solitary abscess, and one massive gangrene. Striking features in these lesions were that the embolus lay just proximal to the

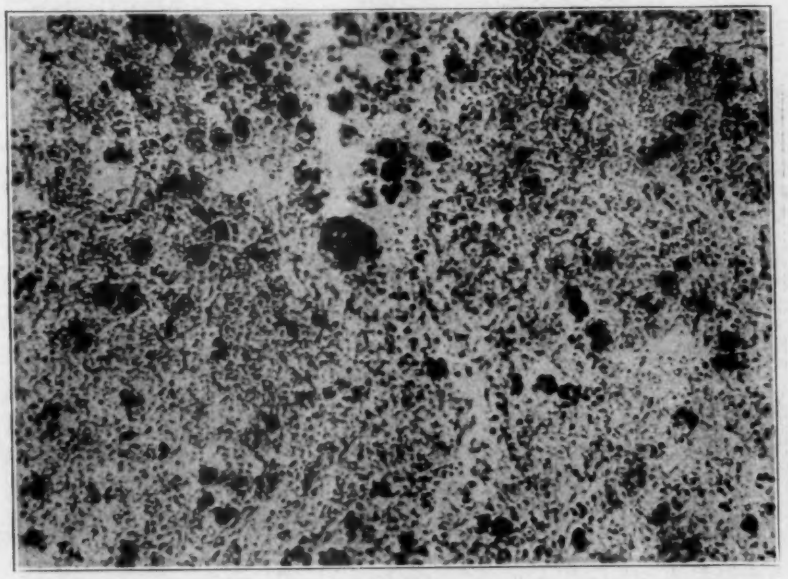

Fig. 5 (dog 17).—Photomicrograph of the embolized sector of the lung twelve days after bland embolism and septic intrabronchial insufflation. Note the loss of tissue vitality.

lesion and embedded in normal lung, and that the lesion was strictly confined to the territory supplied by the embolized vessel. Elsewhere, in nonembolized parts of the lung, the same effects of the bronchial contamination appeared as in animals not receiving embolus (group 2).

The various alterations which thus appeared in response to a combination of intrabronchial inoculation with sterile embolus are interpretable on a basis of alterations in tissue vitality. Thus, the extreme change, i. e., massive gangrene, represented total and uniform tissue death; solitary abscess formation represented central devitalization plus infection; septic infarct formation showed devitalization of parts only

that were farthest from the bronchial vessels, plus infection; atelectasis was the result of bronchial obstruction from fibrosis of foci of necrosis; and hemorrhagic infarction of the otherwise intact parenchyma of the lung must have occurred from fragility and rupture of the capillary wall.

One factor in these animals to account for this reduction of vitality is embolic obstruction of the pulmonary blood supply, but in group 1 it is shown that such does not occur from embolus alone. Another prominent circumstance is contamination of the bronchial tree with infectious material; but the essential factor here is probably not the direct necrotizing action of the bacteria, for tissue vitality was lost first by the parts farthest from the bronchi, and in the least grade of lesion, hemorrhagic infarction, there was no evidence of infection of the

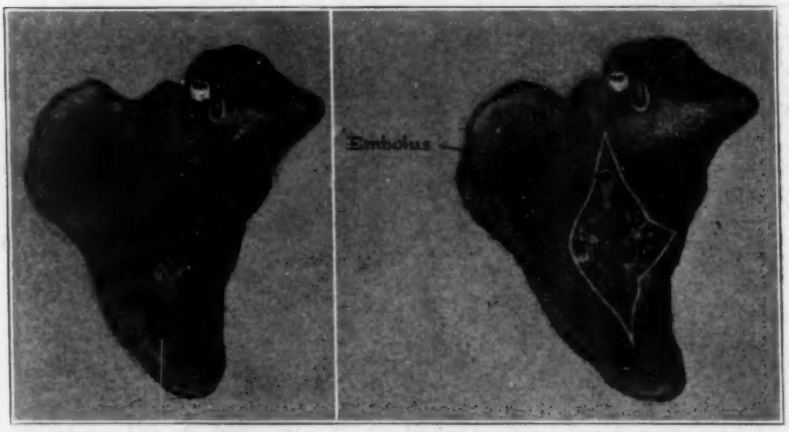

Fig. 6 (dog 18).—Right lower lobe twelve days after bland embolism and septic intrabronchial insufflation. The infarcted area presents foci of necrosis.

parenchyma. Additional vascular occlusion was evidently the factor supplied by the intrabronchial contamination. Thus, bronchitis produced peribronchial congestion, and this jeopardized the blood supply of parts at a distance to the bronchi which after pulmonary embolism rely practically entirely on the bronchial vessels. Of course in addition to vascular occlusion from these two sources, devitalization was contributed to by direct bacterial action to a considerable degree in the severer lesions.

It may be concluded, accordingly, that lung tissue which retains only its bronchial blood supply behaves toward pyogenic infection in a manner similar to that of other tissues having a blood supply of corresponding amount; that is, where the infection is sufficiently virulent focal or diffuse necrosis occurs.

It should be pointed out that the suppurative process produced in the lung by combining bland embolism with bronchial contamination is of a different nature from that which results from a septic embolus. In the former it is diffuse and occupies more or less uniformly the entire embolized sector of lung, since the infection arises in all parts from the bronchial tree, while in the latter it centers at the embolus and lacks infarct distribution.

The principle of ischemia in infections of the lung probably has clinical significance. Thus, it may pertain to postoperative pulmonary complications, since both embolism and bronchial contamination occur

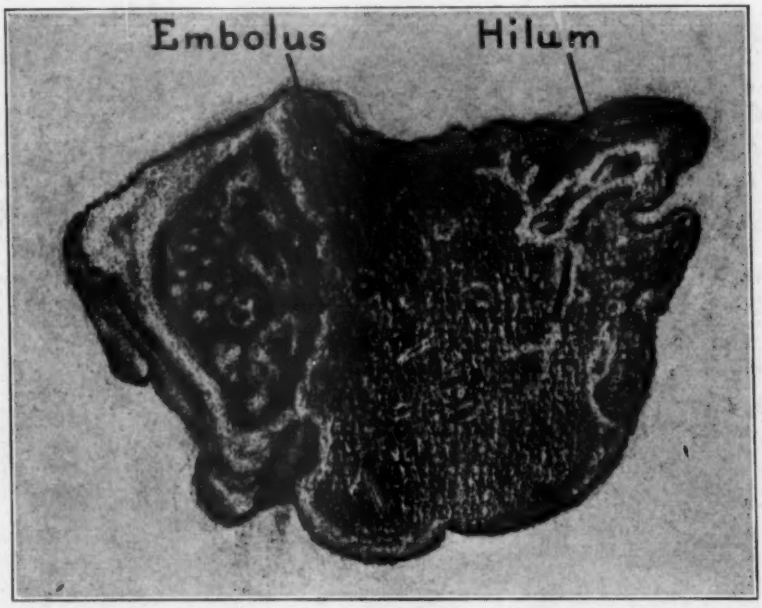

Fig. 7 (dog 14).—Left upper lobe twelve days after bland embolism and septic intrabronchial insufflation. The cut surface of the lobe is seen and presents a large abscess lying distal to the embolus.

in conjunction with surgical operations.[1] If, in the presence of intrabronchial infection, a small fragment of blood clot from near the operative field lodges in the lung, what might otherwise have been an uncomplicated bronchitis or pneumonia may develop into a suppurative lesion. This could occur whether the embolus were sterile or infected and may account for certain pulmonary abscesses following sterile operations.

Thrombosis of a pulmonary arteriole would have the same effect as embolism, and this suggests an explanation for certain other phenomena of suppurative diseases of the lung. Postpneumonic abscess of the lung

may be caused by thrombosis of an arteriole lying within the pneumonic area; indeed, the rarity of arterial thrombosis in pneumonia, as far as we are acquainted with it, makes this the more plausible, since abscess after pneumonia is also rare. Likewise relapses and abrupt changes for the worse that are occasionally seen in pulmonary suppuration, with new extensions of ulceration and gangrene, are probably the result of thrombosis and devitalization of new parts. Empyema complicating pneumonia, especially where cortical "abscesses" are seen and where bronchopleural fistula appears, may be caused by thrombosis of a peripheral cortical vessel.

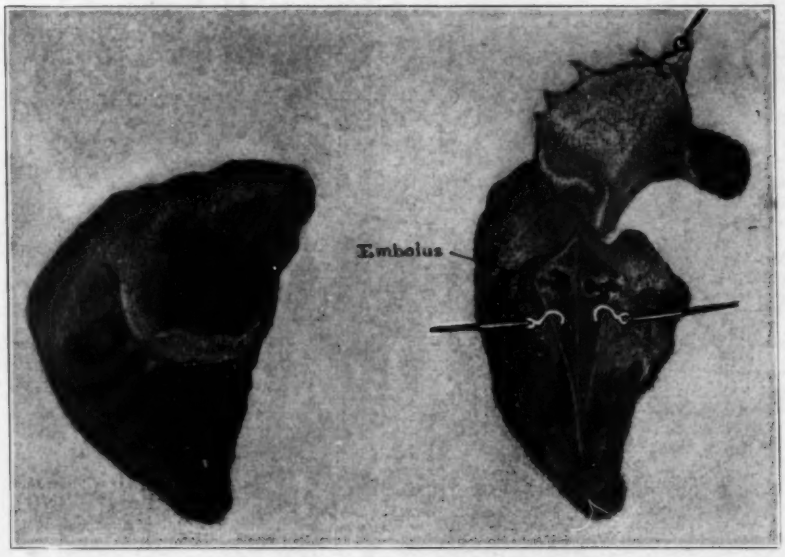

Fig. 8 (dog 25).—Left upper lobe twelve days after bland embolism and septic intrabronchial insufflation. The distal half of the lobe is gangrenous.

It should be emphasized that obstruction of the pulmonary artery in the presence of bronchial contamination does not necessarily lead to softening and suppuration, for this occurred in only four of thirty-six dogs. Also, there is no appreciable tendency for localization of infection in the embolized area; indeed, in these dogs pneumonia often existed only in nonembolized parts. Evidently, the bronchi of an embolized zone, since they retain their normal blood supply are no less susceptible to infection and serve to protect the surrounding parenchyma from it in a normal fashion; but once the infection succeeds in invading the parenchyma, it finds ready medium in the devitalized parenchyma.

SUMMARY

Attention was called to the facts that abscess develops much more readily from embolic than from intrabronchial inoculation of the lung, and that the lung appears to be in general much more resistant to necrosis and suppuration than are other tissues.

Experimental test was made of the hypothesis: The greater vitality of the lung in pyogenic infections is due mainly to a greater blood supply, and elimination of the pulmonary circulation, as by embolism, reduces the blood supply and tissue vitality to the common level.

It was concluded that the hypothesis is essentially correct. This principle was applied to explain the pathogenesis of certain suppurative diseases of the lungs, viz., postoperative abscess of the lung especially following sterile operations, postpneumonic abscess of the lung and empyema, and relapses in suppurative diseases of the lung in general. Hemorrhagic infarct may have a similar origin.

PULMONARY ABSCESS

AN ANALYSIS OF ONE HUNDRED AND SEVENTY-TWO CASES*

JOHN B. FLICK, M.D.

LOUIS H. CLERF, M.D.

ELMER H. FUNK, M.D

AND

JOHN T. FARRELL, JR., M.D.

PHILADELPHIA

Suppurative lesions in the lungs result from pyogenic organisms entering by way of the air passages and the blood stream, or by direct extension from contiguous structures. The term pulmonary suppuration has been used rather indiscriminately to include both abscess and bronchiectasis and while these lesions may be associated, an effort should be made to differentiate them clinically. The term pulmonary abscess as used here refers to the circumscribed suppuration which eventuates in cavity formation, softened tuberculous areas and bronchiectasis being excluded. Among 172 cases which constitute the basis of this report, no abscess due to the aspiration of a demonstrable foreign body or secondary to new growth has been included. These types of pulmonary abscess have certain distinctive pathologic and clinical features which call for separate consideration. Reference will be made to them when the diagnosis is considered.

Among the 172 cases in our group, 108 occurred in males (62.8 per cent) and sixty-four in females (37.2 per cent). The age of the patients varied from 1½ to 66 years, the average being 31 years. The percentage of distribution of the cases by decades is as follows: first decade, 6.4 per cent; second decade, 10.5 per cent; third decade, 27.9 per cent; fourth decade, 30.8 per cent; fifth decade, 18.6 per cent; sixth decade, 3.6 per cent and seventh decade, 2.3 per cent. While pulmonary abscess may occur at any age, one half of the cases in our series occurred in patients between 20 and 40 years. This is in contrast to the predominance in the earlier years of life of the pulmonary suppuration due to aspirated foreign body, and the increasing frequency in later years of pulmonary abscess associated with new growth.

ETIOLOGY

Etiologically, the cases in this series fall in three main groups:

Pulmonary Abscess Following Surgical Operation.—This group includes 121 of the 172 cases, or approximately 70 per cent of the

* From the Jefferson Medical College Hospital.

series. The operations were: (*a*) tonsillectomy, ninety-seven instances (general anesthesia in eighty-eight, local anesthesia in four, anesthesia not stated in five); (*b*) oral operations, such as tooth extraction, etc., ten instances (general anesthesia in seven, local anesthesia in three); (*c*) operations in other parts of the body, e.g., appendectomy, herniorrhaphy, etc., fourteen (general anesthesia in eight, anesthesia not stated in six). Tonsillectomy constituted 56 per cent and tonsillectomy and oral operations 62 per cent of all the cases.

Pulmonary Abscess Following Acute Infection of Respiratory Tract.—This group includes forty-three of the 172 cases, or approximately 25 per cent of the series. Difficulty was encountered in determining the character of the respiratory disease preceding the onset of the pulmonary abscess. According to the patient's history, an acute infection of the respiratory tract, variously called "an acute cold," influenza, acute bronchitis, preceded the symptoms of abscess in twenty-two instances, or approximately 13 per cent of the whole series. Pneumonia was stated to precede the occurrence of abscess in sixteen instances or 9.3 per cent of the series. In five of these cases there was a complicating pleurisy, and in one a rib resection had been done for empyema. In two cases each, a simple acute pleurisy without effusion and bronchopneumonia were stated to have preceded the onset of pulmonary abscess.

It is our opinion that the acute respiratory lesions considered as antecedent to the occurrence of abscess of the lung probably represent variations in the severity of the initial manifestations of the pyogenic infection. Occasionally, with widespread pyogenic infection, the acute onset and diffuse character of the pulmonary lesion grossly resemble lobar pneumonia. Later, with localization and distinct abscess formation, the sequence of events may easily be misinterpreted as abscess complicating or following lobar pneumonia.

Miscellaneous Group.—In this group the abscess was said to follow a chest injury (automobile accidents, stab wound with empyema) in two instances, drowning accidents in two instances, poisoning from sewer gas in one instance, and from unknown causes in three instances.

The infection in pulmonary abscess is usually polymicrobic. Our associate, C. J. Bucher, has in preparation the complete report of the bacteriologic observations in our patients. His studies have been made on specimens collected by direct bronchoscopic aspiration or at operation. Spirochetes and fusiform bacilli are commonly found in association with pyogenic cocci.

SITE OF THE ABSCESS

While pulmonary abscess may be single or multiple and occur in any part of the lung, they were found to be localized in one lobe in

79.3 per cent, in two lobes in 19.5 per cent, and in three lobes in 1.2 per cent of the 169 cases of our series in which accurate localization was attempted by combined physical, roentgenologic and bronchoscopic examinations. It is often stated that the lower lobes, and especially the right, are more frequently involved. In our experience, involvement of the upper lobe is more common.

CLINICAL MANIFESTATIONS

F. T. Lord has pointed out that the symptomatology of the postoperative and nonoperative group does not vary materially. This has been our experience. One of us (Clerf [1]) analyzed carefully the time of onset and the development of the symptoms after tonsillectomy in forty-seven cases. The time of onset of symptoms varied from one to thirty-five days. The average time of occurrence of definite symptoms (pain, fever, chills or chilliness, cough with or without expectoration,

TABLE 1.—*Distribution of Pulmonary Abscesses*

Monolobar Lesions (134 cases)			
Right upper lobe	49	Left upper lobe	30
Right middle lobe	10	Left lower lobe	23
Right lower lobe	22		
Multilobar Lesions (35 cases)			
Unilateral (33 cases)			
Right middle and lower lobes	14	Left upper and lower lobes	11
Right upper and lower lobes	4		
Right upper and middle lobes	4		
Bilateral (2 cases)			
Right middle and lower lobes and left upper lobe	1		
Right upper and middle lobes and left upper lobe	1		

and hemoptysis) was seven and two-tenths days. Often the patient was listless and irritable for several days before the onset of distinct symptoms. A brief period of malaise with general weakness and slight fever is not uncommon after uncomplicated tonsillectomy. Not infrequently it is stated that the patient "caught a cold" while at the hospital or more often, when returning home.

Pain referred to some part of the chest was the most commonly observed early symptom. It is described as sharp, stitchlike, or stabbing, made worse by coughing or deep breathing, and suggests the pain of pleurisy. In one case, it came on twenty-four hours after operation. In twenty-two cases (46 per cent), pain was the first symptom and was observed within four days following operation.

Fever, without chill or chilliness, occurred as the first symptom in eight cases (17 per cent). It is present at some time or other in practically all cases, and usually subsides after adequate drainage has been

1. Clerf, L. H.: Lung Abscess Following Tonsillectomy, Atlantic M. J. **31**: 911 (Sept.) 1928.

established. Continuance of fever after drainage has spontaneously occurred suggests either an extension of the infective process or defective drainage. A recrudescence in the later stages of the disease usually indicates interference with drainage. Fever with chills or chilliness was noted as the first symptom in six cases (13 per cent). Severe rigors, uncommonly observed, usually indicate extension of the pulmonary lesion.

Cough, without expectoration, was the first complaint in eleven cases (23 per cent). With rupture of the abscess into a bronchus, cough becomes a frequent and distressing symptom and is associated with expectoration of purulent material. The earliest occurrence of purulent expectoration was five days after operation, a large quantity of fetid pus being evacuated. The longest interval was forty-eight days after operation. In twelve cases (25 per cent) purulent expectoration was observed on or before the seventh day.

The material first expectorated varied in quantity and in appearance. In several cases a large quantity (from 1 to 2 cupfuls) of dark fetid material suggesting decomposed blood was expectorated within several hours.

Hemoptysis as a first symptom did not occur in any of the cases in this special group. In one instance a considerable quantity of blood was expectorated on the seventh day.

The onset and development of symptoms (the clinical picture) are more important in the diagnosis in the individual patient than the total of the symptoms occurring in the individual or in the group. The following tabulation prepared from the history taken on admission in 114 cases gives some idea of the relative frequency of the symptoms: cough, 99.1 per cent; expectoration, 86.8 per cent; pain, 71.5 per cent; hemorrhage, 44.7 per cent; dyspnea, 13.1 per cent, and fever, with or without chilliness or chills, 62.2 per cent.

The blood count revealed a great variation in the number of leukocytes, a count within the normal range being not uncommon. A moderate secondary anemia was common; a pronounced anemia occurred in about 20 per cent of the cases.

DIAGNOSIS

The determination of the presence and the location of a pulmonary abscess requires a consideration of the history, symptoms and signs, studies of the sputum, roentgenologic observations and bronchoscopy. The occurrence of cough and fever after operation, especially about the upper respiratory tract, should focus attention on the possibility of pulmonary abscess. The sudden appearance of purulent expectoration, or the occurrence of a severe paroxysm of cough during which considerable pus is expectorated, is highly significant, although this may

occur in perforating empyema and perforating subdiaphragmatic abscess. The presence of elastic fibers in the sputum in the absence of tubercle bacilli is evidence of a nontuberculous destructive lesion. The physical signs are not distinctive. The small deep-seated abscess may give rise to marked symptoms and indefinite signs. In the larger and more superficial abscesses the signs are usually those of consolidation which may occur in any part of the chest. A pleuritic friction sound is common, though frequently overlooked. Distinct cavity signs are so infrequent in pulmonary abscess that their absence should have no weight in diagnosis. The roentgen and bronchoscopic examinations are invaluable in the complete diagnostic study and aid particularly in the localization of the lesion. Such localization is essential in the consideration of therapy.

The conditions to be differentiated from pulmonary abscess are:

1. Tuberculosis. Pulmonary abscess, especially of the upper lobes, may easily be mistaken for pulmonary tuberculosis unless the history, the character of the sputum, including the presence of tubercle bacilli, and the roentgenologic observations, are carefully considered. Patients with pulmonary abscess are not infrequently referred to tuberculosis sanatoriums.

2. Bronchiectasis. In recent cases of pulmonary abscess, the differentiation from bronchiectasis is usually not difficult. The history and the observations on physical, roentgenologic and bronchoscopic examinations are usually conclusive. In the cases of long standing, however, the lesions of abscess and bronchiectasis present so much in common and so frequently co-exist that the differentation may be difficult (fig. 1*A* and *B*).

3. Pulmonary suppuration due to aspirated foreign body. This is more common during the early years of life, but may occur at any age. The history may be inconclusive and the latent interval between aspiration and the development of pulmonary symptoms may be misleading. The symptoms and signs may resemble those of nonforeign body abscess; however, in cases of foreign bodies the asthmatoid wheeze, the tendency of the signs to change with the shifting of the foreign body and the occurrence of signs of bronchial obstruction are commonly found. The roentgenologic and bronchoscopic examinations are conclusive.

4. Interlobar empyema. The physical signs are most marked in the region of the interlobar septum; there may be some displacement of the heart, and the sputum, if purulent, rarely contains elastic fibers. The roentgenologic observations are important.

5. Neoplasm. Diagnostic bronchoscopy is the only method by which primary new growth in the lung or pulmonary abscess secondary to pri-

mary new growth can be recognized with certainty unless extrathoracic metastases are present.

6. Syphilis and the mycotic infections. These are rare. The history, concomitant evidence of syphilis or of the mycoses in other parts of the body, the Wassermann test, and the studies of the sputum are important.

7. Pulmonary gangrene. The distinction is not difficult in the typical case with marked fetor of the breath and sputum and profound systemic disturbance. In other instances the lesions of abscess and gangrene so closely resemble each other that differentiation is not possible. The finding of spirochetes and fusiform bacilli does not serve to differentiate the two conditions.

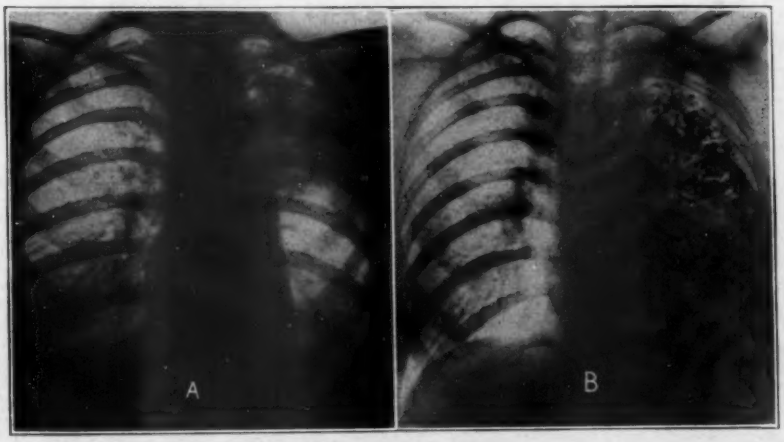

Fig. 1.—Post-tonsillectomic abscess involving the upper lobe of the left lung. *A*, a roentgenogram made after admission of the patient to Jefferson Hospital, shows a single abscess with multiple cavities. Bronchoscopic treatment was instituted with marked improvement in the acute symptoms; surgical intervention was delayed because of this improvement and later, when resorted to, was probably inadequate. *B* is a pneumonogram demonstrating development of bronchial dilatations throughout the left lung. Thoracoplasty is indicated for the bronchiectasis.

PROGNOSIS

F. T. Lord [2] stated that the expectation for life of patients with pulmonary abscess has never been accurately determined, and from an analysis of a large group of cases concluded that the theoretical outlook in unoperated pulmonary abscess may be estimated as a mortality of about 74 per cent. Lord estimated that under medical treatment alone recovery occurs in about 11 per cent, and incomplete recovery

2. Lord, F. T.: Diseases of the Bronchi, Lungs and Pleura, ed. 2, Philadelphia, Lea & Febiger, 1925, p. 460.

occurs in about 15 per cent of the cases. Among 172 patients under our observation since 1923, eleven are considered as untreated because they were either referred for diagnosis only, securing treatment elsewhere, or because they have so recently come under observation (1 case) that an analysis of the present status cannot be made. Among the remaining 161 patients treated medically, bronchoscopically or surgically, eighty-one recovered (50.3 per cent), forty-eight were improved (29.8 per cent), eight were unchanged (5 per cent), two had a recurrence after apparent recovery (1.2 per cent) and twenty-two died (13.7 per cent). The prognosis is unquestionably influenced by a number of factors:

1. The severity of the pyogenic infection. In the presence of a virulent infection and widespread purulent pneumonia, or when multilobar abscesses or complications are present, the prognosis is grave.

2. The age and previous condition of the patient. These factors are important, especially in the group in which surgical intervention is indicated.

TABLE 2.—*Age of Patient in Relation to End-Result*

Age Period	Recovery	Improved *	Unchanged	Death	Recurrence	Totals
1–10	8	1	1	1	0	11
11–20	8	7	0	2	0	17
21–30	21	15	3	7	1	47
31–40	23	15	2	8	0	48
41–50	17	6	2	3	1	29
over–50	4	4	0	1	0	9
Totals	81	48	8	22	2	161

* By improved is meant marked relief from subjective symptoms, diminution in the abnormal physical and roentgen changes, and marked clearing of the process on bronchoscopic examination.

3. The location of the abscess. Centrally located abscesses are amenable to bronchoscopic treatment, while peripherally located abscesses usually require surgical intervention.

4. The occurrence of complications. Cerebral abscess, cerebral embolism, hemorrhage, suppurative pericarditis, acute diffuse pneumonitis and endocarditis are all complications which feature in the high mortality rate.

5. The duration of the disease before bronchoscopic and surgical treatment is instituted.

6. The care with which patients are selected for the bronchoscopist and the surgeon. Obviously the sine qua non to recovery is adequate drainage either through the air passages or by external incision.

ROENTGENOLOGY IN DIAGNOSIS AND LOCALIZATION

The roentgenographic appearance of pulmonary abscess varies, depending on the stage of the disease, the location, and the presence or absence of complications, notably changes in the pleura.

Before drainage occurs, the involved area appears as a homogeneous density with poorly defined margins. In this stage the appearance is that of consolidation, and when the process follows pneumonia it is considered as delayed resolution. Acute suppurative pneumonitis may be mistaken for pneumonia.

Softening of the tissues and evacuation of the pus through a bronchus gives the roentgen appearance of a cavity containing fluid and air surrounded by a zone of increased density. Change in body position alters the relation of the fluid level in the cavity. The relative sizes of the inflammatory zone and the cavity vary greatly.

The conditions to be differentiated roentgenologically from pulmonary abscess are:

1. Tuberculosis. In tuberculosis with cavity formation there is usually an antecedent history of tuberculosis, the cavity commonly is apical, and there is often evidence of tubercle formation in the opposite lung. Tuberculous cavities rarely contain fluid in great quantity, while fluid is usually demonstrable in pulmonary abscess. Multiple cavity formation is more often demonstrable in tuberculosis than it is in abscess.

2. Neoplasm. Abscess secondary to pulmonary new growth, especially neoplasm of the bronchus, gives rise to no characteristic roentgenogram unless pulmonary metastases are present.

3. Bronchiectasis. Bronchiectasis uncomplicated by extensive changes of the pulmonary tissues is readily distinguished roentgenologically from pulmonary abscess (fig. 2). In this type, cavity formation is not evident on the simple roentgenogram; the increased markings are usually diffuse and occur in the lower portion of the pulmonary fields as an increased haze. The instillation of iodized oil in these cases reveals saccular or cylindric dilatations of the bronchi. Dilatations of the bronchi occurring as a result of pulmonary suppuration of long standing are not readily differentiated from their cause because they are accompanied by marked tissue changes producing on the roentgenogram a dense shadow in which the outlines of the cavities are lost. Pneumonography after bronchoscopic aspiration is the only method which will indicate the exact anatomic change and reveal the cavities which are present (fig. 1).

4. Interlobar empyema. Interlobar empyema is often differentiated with difficulty from pulmonary abscess. Before rupture, the interlobar collection of fluid presents a similar picture to that of abscess before cavity formation. After rupture and drainage, it may roentgenographically simulate the cavity of abscess. The history of a preceding pneumonia with the occurrence of the changes in the vicinity of the fissures is of value.

The best localization from the surgical standpoint is by the roentgen method, using postero-anterior and lateral exposures. In abscess of the upper portion of the upper lobe, localization in the lateral view is not always satisfactory and dependence must be placed largely on the physical examination.

Fluoroscopic localization with the patient in the position in which the operation is to be performed is of value, and should be done in the presence of the surgeon. Localization in relation to ribs is preferable to skin localization.

Determination of the most superficial portion of the abscess is most important because at this point the surgeon finds pleural adhesions if they are present.

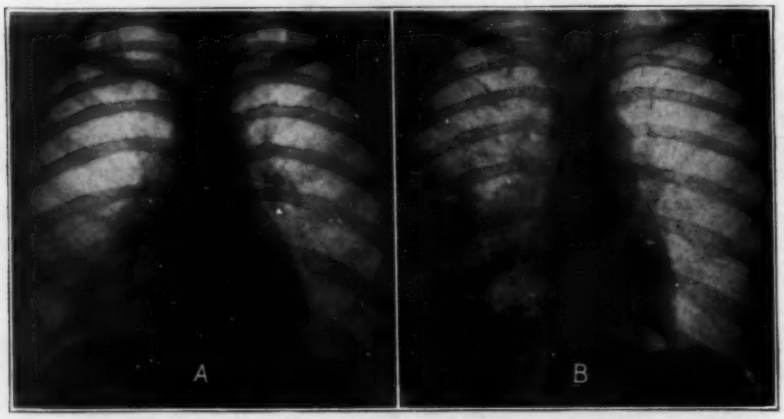

Fig. 2.—Bronchiectasis of the right lung of two years' duration complicated by the development of a pulmonary abscess. *A*, a roentgenogram made before development of the abscess, shows extensive changes in the right lower lobe. *B* shows an abscess with fluid level which cleared up completely following external drainage. The wound healed. Thoracoplasty is indicated for the bronchiectasis.

In the typical abscess with cavity and fluid, the foregoing method is sufficient for localization. When the abscess is long standing and complicated by adjacent tissue changes and thickening of the pleura, bronchoscopic pneumonography is of value. Under fluoroscopic guidance it is possible to control the quantity to be instilled and to direct the bronchoscopist to the area of greatest involvement. Care must be taken that the pneumonogram does not mislead one; sometimes the oil collects in the parenchyma in a localized area in such a way as to simulate an abscess. Distinguishing features are that there is no fluid level and the iodized oil occupies an area free from disease on the roentgenograms made before the instillation.

The progress of the patient under treatment is readily determined by serial roentgenograms. The occurrence of complications such as new areas of involvement, metastatic abscesses or pleural changes may be recognized.

GENERAL CONSIDERATIONS OF TREATMENT

Medical treatment comprises rest, symptomatic care, attention to the diet and measures to improve the general condition of the patient. Medical treatment alone is indicated in the early acute phase of pyogenic infections before abscess formation has occurred. In other instances it is combined with bronchoscopic or surgical treatment or both. Caution is necessary in the administration of cough sedatives which favor stagnation, a factor in prolonging suppuration to a chronic or fatal issue. Postural drainage is important in supplementing bronchoscopic drainage in pulmonary abscesses located near the hilum and in communication with the tracheobronchial tree. In this location the abscess tends to drain spontaneously into the large bronchi but is frequently prevented from so doing by ciliary denudation, obstructing granulations or the weight and bulk of retained secretions. Bronchoscopic drainage is particularly indicated in this type of case. When the abscess is peripherally located in connection with only small terminal bronchi, drainage can rarely be established apart from external operation.

Our general attitude is to treat patients with pulmonary abscess conservatively, including bronchoscopy, unless surgical intervention is definitely indicated at the time the patient comes under observation. The possible advantage of surgical measures is considered in every patient, but they may be spared the external operation by careful bronchoscopic treatment. Conservative measures may prepare the patient for surgical intervention, but on the other hand, the disease should not be allowed to go on indefinitely until fibrosis and bronchiectasis occur and render the ultimate surgical intervention difficult and unsatisfactory. The whole problem of the treatment in the individual case requires close cooperation of the internist, roentgenologist, bronchoscopist and surgeon.

Artificial pneumothorax, in our opinion, is not only unsatisfactory but dangerous. Since the principal object of therapy in pulmonary abscess is to secure adequate drainage, it is difficult to understand the rationale of treatment by induced pneumothorax. In tuberculosis, rest and immobilization of the lung are primary considerations, while in abscess, drainage is the sine qua non to recovery. Whittemore and Balboni [3] reported that among eighteen patients treated by this method,

3. Whittemore, W., and Balboni, G. M.: Nontuberculous Bronchopulmonary Suppurative Lesions: Results of Treatment by Artificial Pneumothorax, Arch. Surg. **16**:228 (Jan.) 1928.

two were completely cured, two were temporarily improved, three died from hemorrhage from the lung during treatment, five developed empyema, of which one died. These observers conclude that the value of artificial pneumothorax in the treatment for pulmonary abscess is questionable.

Small transfusions of whole blood are of value in patients with marked secondary anemia, especially in the preparation for operation and in the after-care of those treated surgically.

BRONCHOSCOPY IN DIAGNOSIS AND IN TREATMENT

The ability of the bronchoscopist to inspect the interior of the larger bronchi and the orifice of the bronchial subdivisions renders bronchoscopy a valuable aid in diagnosis. Pus observed coming from the orifice of a bronchial subdivision is positive evidence of the presence of suppuration; whether the process is abscess of the lung, bronchiectasis or purulent bronchitis must be determined in conjunction with other methods of diagnosis.

The importance of a diagnostic bronchoscopy in all cases of pulmonary abscess, unless distinctly contraindicated, irrespective of the method of treatment to be employed has been repeatedly demonstrated. Abscess of the lung may be secondary to a neoplasm of the bronchus or an overlooked nonopaque foreign body. In either of these conditions, external drainage would be of questionable value. Bronchoscopy can positively establish the presence of bronchial obstruction and in the case of new growth a specimen of tissue can be removed for histologic examination. If the lesion is benign, it can often be removed bronchoscopically; if a foreign body is present, its removal will achieve cure in practically every case.

The accurate localization of a suppurative process occasionally presents difficulties. Often one cannot determine if the lesion is in the lower portion of the upper lobe or in the upper portion of the lower lobe. The bronchoscopist can definitely ascertain whether pus comes from one or the other bronchus, and in this way he can localize the suppuration with relation to the lobes of the lung and not infrequently to the subdivisions of one of the bronchi. In certain cases of pulmonary abscess it may become necessary to resort to pneumonography for the accurate localization of the cavity. Instillation of iodized oil into the cavity is often extremely difficult since the communication between the abscess and the draining bronchus is often tortuous and filled with secretion, granulation tissue and swollen and edematous mucosa. Methods of instillation which are dependent on gravity are rarely successful in these cases. The best results are obtained by the bronchoscopic method of instillation of the iodized oil performed on the fluoroscopic table so that the aid of the fluoroscopist may be secured

in determining the quantity of material to be instilled, also to ascertain if a certain bronchial subdivision actually communicates with the abscess cavity.

Bronchoscopic aspiration, in trained hands, can be safely and quickly carried out, and, in properly selected cases of pulmonary abscess it is one of the most efficient methods of treatment at our command. The excellent results obtained by a large number of bronchoscopists justify the opinion that bronchoscopy should be one of the methods of treatment to be considered in every case of pulmonary abscess.

Adequate drainage, which is the most important factor in the spontaneous recovery of these patients, can often be secured by bronchoscopy. This is accomplished by the removal of obstructing masses of granulation tissue, by the aspiration of the large quantity of pus which overtaxes ciliary activity (Jackson) in the smaller bronchi and by the removal of secretions from the abscess cavity with the aid of small, flexible-tipped, aspirating tubes.

Every case of abscess is not suitable for bronchoscopic aspiration; this must be determined by careful study of the patient by the internist, the roentgenologist and the surgeon. The matter of teamwork in determining the proper method of treatment and in following the subsequent progress of the patient has been discussed elsewhere. Its importance cannot be overemphasized (fig. 3).

Duration of the disease need not necessarily be a determining factor in deciding on bronchoscopy; in recent cases of abscess there is invariably more favorable response than in those of prolonged duration. In the latter cases, however, remarkable results have been obtained following a course of bronchoscopic aspiration.

In our series, 127 patients with abscess of the lung were referred for bronchoscopic treatment. This group does not include those cases in which surgical intervention was indicated when the patients first came under our observation, cases in which a diagnostic bronchoscopy was done preliminary to external drainage or cases of abscess of the lung secondary to demonstrable bronchial foreign bodies.

From an etiologic standpoint, the group was subdivided as follows: abscess of the lung following tonsillectomy, seventy-seven cases; abscess of the lung following operations other than tonsillectomy, twelve cases; abscess of the lung following extraction of teeth but in which no foreign body could be found, eight cases, and abscess of the lung complicating acute infection of the lower respiratory tract, thirty cases. In the group of cases of abscess following tonsillectomy, a series of fifty-eight cases that was reported in a previous paper is included.[1]

Of the 127 cases, the lesion involved the right lung in seventy-five and the left lung in fifty; there was bilateral involvement in two cases.

Monolobar involvement occurred in 104; two lobes were involved in twenty-one; in the bilateral cases three lobes were involved. The lobar distribution is shown in table 3.

The lobar distribution in the post-tonsillectomic cases corresponds closely to that reported in a previous series. It is interesting to note that of the twelve postoperative cases (extra-oral), eleven involved the right lung.

In this group, six patients are still under bronchoscopic treatment. In 121 patients, bronchoscopic treatment was discontinued because of complete recovery, improvement, lack of improvement, reference to the surgeon for external drainage, or death. The following tabulation is based on the results obtained in 121 cases: well, sixty-six (54 per cent); improved, sixteen (13 per cent); no improvement, eight (6 per cent); referred to surgeon, twenty-eight (23 per cent), and died, three (2.4 per cent).

Fig. 3.—Roentgenograms of a patient, aged 3½ years, admitted to the Chevalier Jackson Bronchoscopic Clinic, Jefferson Hospital, because of high fever, persistent cough and some difficulty with breathing. There was a history of pneumonia (?) four months before admission. The child was extremely ill; fever was septic in type, at times reaching 106 F.; there was marked anemia, hemoglobin being 32 per cent and red blood cells 2,300,000 per cubic millimeter. *A* is a roentgenogram made on admission of the patient by Dr. W. F. Manges, who reported as follows: "There are multiple foci of suppuration in both lungs. The middle and lower lobes are involved on the right side and the upper lobe is involved on the left side. There is evidence of cavitation." Bronchoscopy was advised and aspiration was instituted with definite improvement. A total of eight bronchoscopic aspirations were carried out during a period of twenty-six days. *B* was made five days after the last bronchoscopic aspiration; no evidence of cavity formation was found, and slight peribronchial thickening remained. The patient was discharged well.

The best results are obtained when bronchoscopic treatment is instituted early in the disease. Jackson, McCrae, Meyer and others have repeatedly stressed this point. Its importance is well demonstrated in these cases. Of the entire group of 121 patients, sixty-two (51 per

cent) were treated bronchoscopically within three months after the onset of symptoms. Of these, forty-four are well, nine were referred to the surgeon for external drainage, six are improving, one remained unchanged and there were two deaths. This gives a recovery rate of 70 per cent. It is probably true that certain of these patients would have recovered spontaneously under medical care alone. It may be recalled, however, that the majority of the patients referred to the bronchoscopic clinic for treatment had been under medical care for a time, and it was the opinion of their medical advisers that bronchoscopy should be instituted, presumably because of the lack of sufficient improvement to warrant continuation of medical treatment alone.

In a comparative analysis of the cases referred to the surgeon and those in which bronchoscopy has been successful, nothing unusual was observed so far as lobar distribution of the suppurating process was concerned; nor was there any remarkable disproportion between the ages of the patients in the group of cases occurring after operative

TABLE 3.—*Lobar Distribution*

Monolobar Lesions			
Right upper lobe	37	Left upper lobe	23
Right middle lobe	4	Left lower lobe	19
Right lower lobe	21		
Unilateral Multilobar Lesions			
Right upper and middle lobes	2		
Right lower and middle lobes	11		
Bilateral involvement	2	Left upper and lower lobes	8

procedures. In the cases of abscess following infections of the respiratory passages it was noted that the average age of the patients referred to the surgeon was 41 years, as compared with 34 years, the average age of patients who recovered following bronchoscopy.

An important consideration in treatment is the avoidance of exposure of the patient to acute respiratory infections. In four instances, patients who were considered practically well were discharged from the hospital at a time when, unfortunately, acute infections of the upper respiratory tract were prevalent. Each of these patients contracted an acute cold, and subsequently there was reinfection with recurrence of the pulmonary lesion (fig. 4). In three of these, bronchoscopic aspiration was again instituted but without benefit, and they were referred to the surgeon for external drainage. In the remaining case, bronchoscopy was contra-indicated by reason of pleural involvement.

SURGICAL TREATMENT

The indication for surgical intervention is the failure to bring about a cure within a reasonable length of time by the more conservative measures. In a small percentage of cases when the patient first comes

under observation, the abscess is so close to the wall of the chest that it is safer to resort at once to external drainage than to risk the development of an empyema. The type in which the abscess cavity has a markedly fibrosed wall will probably always require operation, but nothing is lost and often a great deal gained by bronchoscopic drainage and other conservative measures until the maximum benefit of such treatment has been obtained.

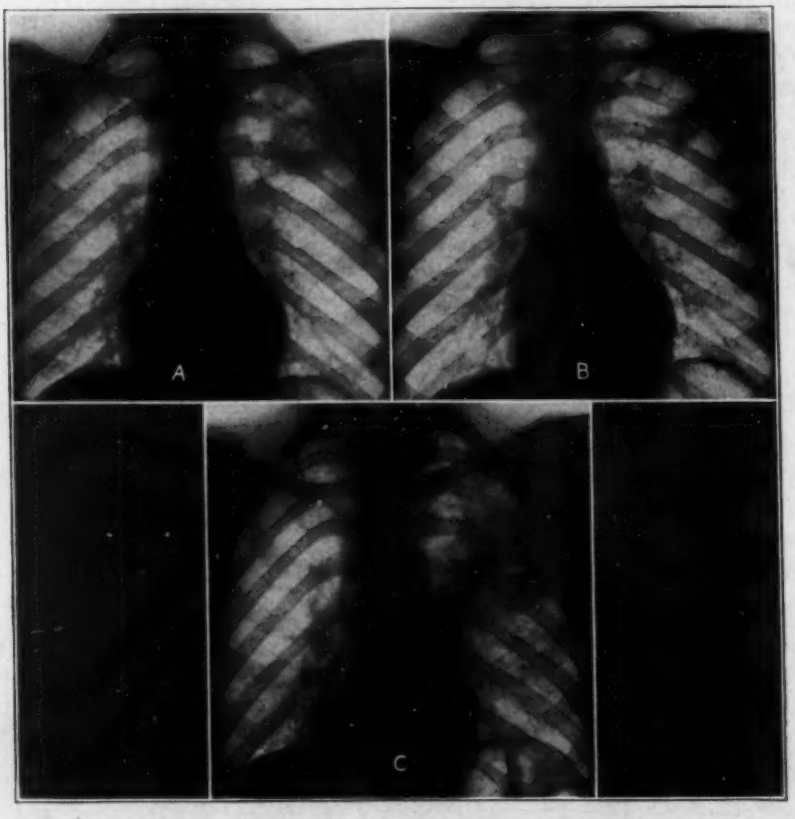

Fig. 4.—Roentgenograms of a man, aged 29, who developed pulmonary symptoms following tonsillectomy under general anesthesia. He was admitted to the bronchoscopic clinic for treatment six weeks after onset of symptoms. *A* is a roentgenogram made on admission of the patient to the Jefferson Hospital. There is an abscess in the posterior portion of the upper lobe of the left lung. Bronchoscopic aspiration was instituted with satisfactory results. After nineteen treatments were given, cough and expectoration were negligible, and the chest seemed clear. *B* was made just before the patient was discharged. The inflammatory changes in the left upper lobe have almost completely cleared up. *C* was made two months after discharge from hospital. There has been a recurrence of the pulmonary infection with extensive changes in the upper lobe. Bronchoscopic treatment was again instituted without benefit. Surgical drainage was carried out with complete recovery of the patient.

In the group of twenty-nine patients operated on, bronchoscopic treatment had been tried unless contraindicated or unless operation was clearly the procedure of choice. We have not considered the duration of the abscess as a prime determining factor in the selection of the method of treatment, since some cases of long standing have responded to bronchoscopic drainage, while others of but four or five weeks' duration have required operation. The shortest duration of the disease in the group of patients treated by external drainage was four weeks. The average duration in all the patients thus treated who made complete recoveries was five and eight-tenths months; in those who died, seven and three-tenths months.

The selection of the proper time for operation is important. This has been stressed by Miller and Lambert,[4] who believe that external drainage in the acute phase of the disease is extremely dangerous. In some of their cases in which the abscess was opened during this stage there followed a wide extension of the pneumonic process with a fatal termination in from three to seven days. At autopsy, they found "a widespread massive involvement of the entire lung or both lungs, in which the bronchi were filled with pus and the alveoli either showed the changes of an acute pneumonia or were swollen, edematous and infiltrated with leukocytes. In some cases there were multiple small abscesses widely disseminated throughout the lungs."

In two of our fatal cases in which the patients were extremely ill and had large abscesses involving an upper lobe, we had a similar experience—improvement for a few days, then the development of small abscesses disseminated throughout both lungs.

Miller and Lambert were of the opinion that external drainage does not drain the pneumonic process about the central suppurating focus which is present during the acute phase, and that with the establishment of a free opening, the effectiveness of coughing to empty these areas is greatly reduced. With this, we are in accord.

After the abscess has been localized as accurately as possible the exposure is planned, keeping in mind a two-fold object, namely, drainage and obliteration of the cavity. In cases of short duration, obliteration of the cavity will probably take place if adequate drainage is established and maintained for a sufficient length of time, the expansion of the lung and contraction of scar tissue making any plastic procedure unnecessary. Cases of long standing require a more formidable procedure in order to obtain obliteration of the cavity.

As a general proposition an abscess of the upper lobe can best be reached through the anterolateral wall of the chest. In three of our

4. Miller, J. A., and Lambert, A. V. S.: Treatment of Abscess of the Lung, Am. J. M. Sc. **171**:88 (Jan.) 1926.

cases a posterior approach was used, dividing the rhomboid muscles and pulling the scapula outward. In one of these it was evident at operation that an anterior exposure would have been better, as the abscess cavity sloped downward and forward, and this was done subsequently. In the other two the abscess probably could have been reached just as well through an anterolateral incision. It is our feeling that the posterior approach in abscesses of the upper lobe is seldom advisable. In abscesses of the lower lobe the approach is posterior or posterolateral and in abscesses of the middle lobe, anterolateral.

With increasing experience, our views regarding the proper procedure in the surgical treatment for pulmonary abscess have undergone certain changes. We are no longer content with simple drainage in the majority of cases, but believe that something more must be done if a complete cure is to be obtained. Obliteration of the abscess cavity depends on contraction of its wall, as well as on expansion of the lung. This cannot occur in large, superficially located abscesses while part of the abscess wall is held out by the rigid framework of the chest. It is therefore necessary to resect a sufficient portion of the ribs near the abscess to permit this contraction to take place. Three or four inches (7 or 10 cm.) of two or more ribs, depending on the size and location of the abscess, should be subperiosteally resected and then the corresponding intercostal muscle bundles, with the periosteum of at least one rib, removed. Separation of these structures can be simplified by cautiously incising through an intercostal muscle bundle until the line of cleavage is found. In two of our cases the pleural cavity was accidentally opened, but no harm resulted other than the delay of the final stage of the operation.

In this group of twenty-nine patients operated on, nineteen (65.5 per cent) had obliteration of the pleural space in the region exposed. Eight (27.5 per cent) had light adhesions and only two had an uninvolved pleura (6.8 per cent). In none of the cases has suturing been done to bring about the adhesion of the pleural surfaces; dependence has been placed on the irritation of an iodoform gauze pack left in situ for about a week. Empyema occurred in one case. At autopsy there was found, in addition, an acute bronchopneumonia and a diffuse peritonitis. This patient had an abscess of the upper lobe and as far as it was possible to determine at postmortem examination there had been no leakage from the abscess into the pleural cavity.

In fourteen of the twenty-nine patients operated on, drainage of the abscess was accomplished at the primary operation. In recent cases we have been more radical and believe that the final results are better. With ample exposure of the area involved, one can work with greater safety. Whenever possible, a large part of the outer wall of the abscess has been removed. In one instance, a small abscess of the middle lobe

was practically excised in two stages. At the first stage the outer wall was removed with the endotherm knife, and at a second stage the remaining wall was taken away. There was remarkably little bleeding except from the vessels which accompanied the small bronchi and these required ligatures. We believe that the endotherm knife is destined to play an important part in the development of thoracic surgery.

As soon as the abscess is opened it is emptied of its contents to avoid the aspiration of pus into other parts of the lung. One can then explore to determine the extent of the lesion and remove as much as possible of the outer wall. It is sometimes wise to be content with drainage at first and to remove or destroy the wall of the abscess later. Removal or destruction of the wall of the abscess has been accomplished in this group of cases with the endotherm knife, with the electric cautery or with the soldering iron after the method of Graham.[5] A cavity which at first is large soon shrinks if there has been sufficient resection of the ribs over it and an adequate opening made for drainage.

We have discontinued the use of drainage tubes except when we wish to establish a permanent bronchial fistula, and then only after the external wound has partly closed. The cavity should be packed with gauze which, while it permits drainage, obstructs the opening sufficiently to enable the patient to cough effectively and bring up material from parts of the lung not drained through the abscess cavity. This we believe is important in lessening the occurrence of the pulmonary complications which sometimes follow closely the free opening of a large abscess.

In no case have we had secondary hemorrhage or experienced bleeding at operation which was not easily controlled by packing. An ample exposure and a large opening in the abscess cavity lessen greatly the danger from hemorrhage.

In fifteen cases, the abscess was drained at a second stage. The wound was packed with iodoform gauze, and further roentgen studies were made to establish the relative position of the abscess to the area from which the ribs had been removed. We observed that temporary improvement often followed the primary operation, probably due to the compression made by the pack.

Subsequent operations were required in ten cases either because of multiple abscesses or because the primary operation failed to bring about recovery. Some of these patients were operated on a number of times. Where obliteration of the abscess cavity has not kept pace with healing of the wound, we have excised the scar, again exposed widely the diseased area and cauterized it thoroughly. In some instances, it

5. Graham, E. A.: Rôle of Surgery in Treatment of Pulmonary Suppuration, J. A. M. A. **85**:181 (July 18) 1925.

has been necessary to remove regenerated rib; in some the entire procedure has had to be repeated several times, but each time the cavity has been smaller, and finally the remaining fistulas have spontaneously closed as the wound has healed.

We have used local anesthesia alone in nineteen cases, local in conjunction with nitrous oxide anesthesia in eight cases and nitrous oxide or ethylene anesthesia alone in two cases. We prefer local anesthesia alone or local anesthesia with nitrous oxide analgesia to general anesthesia because it is safer not to abolish the cough reflex. With local anesthesia and nitrous oxide analgesia, if the patient wishes to cough, the mask is removed and the operation momentarily suspended. Morphine and atropine are given by hypodermic injection half an hour before the time set for operation.[6]

There were ten deaths in the group of twenty-nine cases (34.5 per cent). This mortality may seem high, but we have not refused to operate on any patient, however ill, if operation has offered any hope. Two died from cerebral embolism which occurred during the course of operation, one under local and the other under general anesthesia. In the former, death occurred suddenly as the operation was being completed. In the latter, a hemiplegia occurred during operation and death took place within twenty-four hours. Abscess of the brain was the cause of death in three patients, two of whom were regarded as doing well at the time of the development of this complication. Two died from multiple small abscesses disseminated throughout both lungs; one from acute bronchopneumonia (autopsy); one from acute bronchopneumonia, empyema and peritonitis (autopsy), and one from the development of an abscess in the other lung with rupture into the pleural cavity and a pyopneumothorax.

It is interesting to note that in this group of twenty-nine cases, nineteen (65 per cent) had the abscess located in the upper lobes, and eight of the ten deaths (80 per cent) occurred in patients having involvement of the upper lobe.

Two patients developed a recurrence of the abscess. In one, it recurred more than two years after apparent recovery, during which time the wound was healed and the patient was practically free from symptoms. This man originally had three abscesses, all showing fluid levels. Two abscesses in the right upper lobe responded to bronchoscopic drainage and have remained cured (fig. 5*A* and *B*). The abscess of the left upper lobe was operated on and apparently cured; but it has recently recurred (fig. 5*C*). The second patient had an abscess of the right lower and middle lobes; both were drained. A permanent bronchial fistula was established in the right middle lobe. He worked

6. Flick J. B.: Lung Abscess, Ann. Surg. **84**:323 (Sept.) 1926.

as a machinist's helper for seven months, then developed a recurrence of the abscess in the right lower lobe. He was again operated on and a permanent bronchial fistula established in the lower lobe. He is now free from symptoms and working as a gardener, but he has two permanent bronchial fistulas. Nine patients (31 per cent) made complete recoveries. Two of these required multiple operations. Three patients recovered with bronchial fistulas, but are free from symptoms and working. This makes twelve patients, or 41.3 per cent, who have

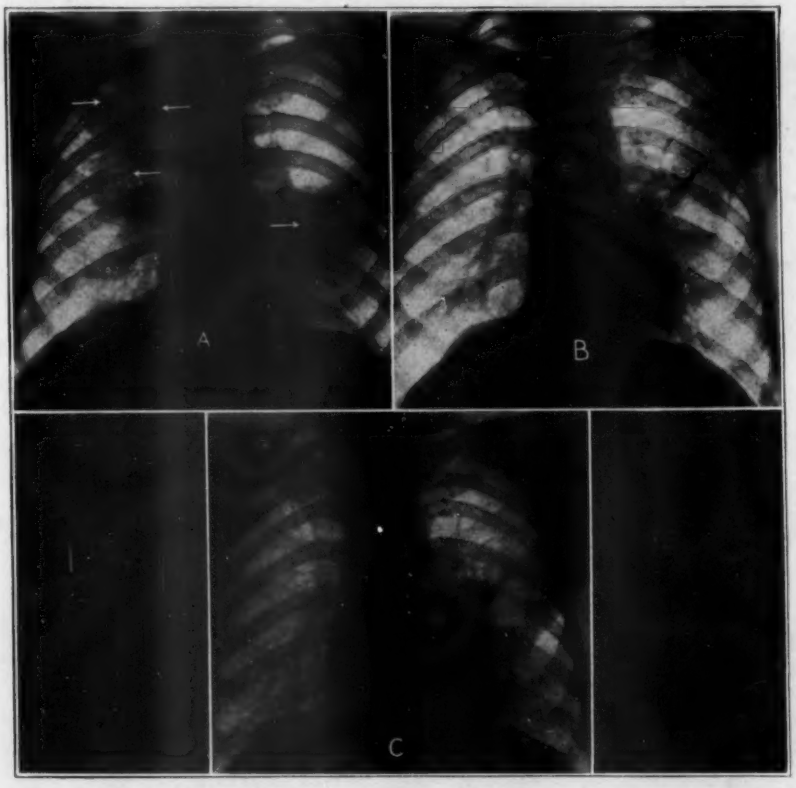

Fig. 5.—Post-tonsillectomic abscess of the lung with multilobar involvement. *A*, a roentgenogram made on admission of the patient to the Jefferson Hospital, shows abscess cavities with fluid levels in the upper and middle lobes of the right lung and in the left upper lobe. Bronchoscopic treatment was instituted; the right lung cleared, but the area of infection in the left lung increased. External drainage was performed with apparent recovery. *B* was made about two years after discharge of the patient from the hospital; both lungs are clear and the patient is clinically well. *C*, made five months after *B*, shows recurrence of the abscess at the base of the left upper lobe. The right side has remained clear.

returned to work. Two patients are improved, but because of bronchiectasis will require thoracoplasty. One of these developed

bronchiectasis as a sequel to a pulmonary abscess (fig. 1); the other developed an abscess as a complication of bronchiectasis (fig. 2). Four are improved but are still under treatment. One patient is unimproved.

CONCLUSIONS

The diagnosis and treatment of abscess of the lung requires the close cooperation of internist, roentgenologist, bronchoscopist and surgeon. The prognosis in a given case is often favorably influenced by the teamwork of this group. A diagnostic bronchoscopy should be done in all cases of pulmonary abscess irrespective of the method of treatment to be employed. The sine qua non in treatment is the establishment of adequate drainage. This may be accomplished in many cases by conservative measures which include repeated bronchoscopic aspirations. The indications for surgical treatment have been outlined. Conservative treatment should not be continued too long if distinct benefit is not obtained, since complications occur which increase the risk and decrease the chances of recovery with surgical intervention.

A CASE OF ABSCESS OF THE LUNG

WITH FILLING OF A CAVITY AND CLOSURE OF A BRONCHIAL FISTULA BY PEDICLE MUSCLE GRAFT

FRANCIS A. C. SCRIMGER, M.D.
MONTREAL, CANADA

REPORT OF A CASE

History.—F. B., a woman, aged 27, was admitted to the Royal Victoria Hospital on Feb. 11, 1929, where a diagnosis of abscess of the upper lobe of the right lung was made. She was first admitted to the medical service in August, 1928, with a diagnosis of tuberculosis of the right upper lobe. After investigation this was changed to abscess of the lung of nontuberculous infection. She complained of cough and foul-smelling sputum; pain in the right side of the chest and a dull ache at the level of the spine of the scapula. She dated the illness to a period following tonsillectomy, which was performed under general anesthesia. In August, 1928, two days after the operation, she suffered from a sharp pain under the scapula. One week later, she began to expectorate foul-smelling sputum. The quantity of sputum increased to 2 or 3 ounces of pus in twenty-four hours, which was usually blood-stained.

Examination.—On examination, there was evidence of consolidation of the right upper lobe. Roentgen examination revealed a cavity in this area which partially filled with iodized oil 40 per cent.

Operation and Course.—On February 14, under local and gas oxygen anesthesia, an incision was first made in the axilla, and a portion of the third rib was removed. Here the pleura was found thin and not adherent. The wound was then closed, and a second incision was made in the back. Portions of the third and fourth ribs were removed. Here a manometer needle showed no excursion during respiration. The pleura was incised with a high frequency knife, and a cavity in the apex of the lung was entered through thickened, firm lung tissue. The extreme apex of the lung was soft. The cavity was widely opened with the high frequency knife and was found to communicate with a large bronchus. The cavity was packed, and the wound was left open.

Following this operation, the sputum cleared and the temperature became normal. The packing was removed on the third day, leaving a cavity situated under the scapula with a large bronchial fistula opening into the inner wall. This was dressed until March 18, 1929, when the superficial wound tended to close, leaving a considerable cavity.

On March 18, with the patient under gas oxygen anesthesia, the previous wound was excised. The cavity was found to be about the size of a hen's egg; in the depth was a fistulous opening large enough to admit a lead pencil. The wall, while tense, was not hard and felt elastic. It was therefore felt to be wise not to cauterize further. The simplest way to obliterate the cavity appeared to be by turning in pedicle muscle flaps, and two of these were fashioned, an upper one from the uncut part of the rhomboid with its pedicle to the upper medial side. It was about 2 inches (5 cm.) long. A lower flap of about the same length was made from the cut portion of the rhomboid. When these were turned in,

they completely filled the cavity. A small rubber drain was put underneath them to act as a path for discharges from the cavity. The rest of the wound was partly closed.

The patient left the hospital on April 16 apparently well. The wound was closed. There was no sputum.

COMMENT

This is merely a preliminary report the only interest of which lies in the apparent closure of a considerable cavity associated with bronchial fistula.

ABSTRACT OF DISCUSSION

ON PAPERS OF DRS. HOLMAN AND MATHES; VAN ALLEN AND ADAMS; FLICK, CLERF, FUNK AND FARRELL, AND SCRIMGER

Dr. Elliott Carr Cutler, Cleveland: By utilizing his previous experiences and knowledge of circulatory phenomena, Dr. Holman has brought a new aspect to the study of pulmonary suppuration.

Chief interest heretofore has been focused on the actual mechanism by which the suppuration is produced, whether aspiratory or embolic; or it has concerned the matter of the bacteriologic agents in the abscess of the lung, whether anaerobic or aerobic.

Now Dr. Holman brings a study of the intimate vascular supply. It would seem that in considering this matter from this point of view we will get certain new and instructive attitudes toward this problem which will be of value to us. Pathologists have long pointed out that the differentiation between gangrene and abscess depends to a certain extent on the occlusion of the vessels. Gangrene seems to occur only when both the pulmonary arterial supply and the bronchial arterial supply is cut off.

I should be interested in asking Dr. Holman whether he had the opportunity to study the bronchial artery in any of the animals in which he had produced suppurative lesions and whether the patency of this vessel bore any relation to the type of lesion produced, i. e., gangrene or abscess. If he has not done this, I would suggest that it might be worth while to produce gangrene by the use of ordinary mouth anaerobes and see whether there is not a difference in the vascular supply.

The other lesson he brings to us is that most instructive point of the enormous collateral circulation that can come through the bronchial artery. I think all thoracic surgeons will be interested in that observation. His injection studies have demonstrated the enormous capacity for adaptation and reserve which is afforded here as elsewhere in the body.

Dr. Emile Holman, San Francisco: We have not used the anaerobic organisms. The same three organisms were used throughout, and were kept under a constant condition of virulence by subculture. We, therefore, thought we were getting a comparable picture in each instance from an infecting organism of constant virulence.

Dr. Willy Meyer, New York: These presentations prove that we all have learned from the pathologist long ago, that if an infectious embolus is thrown into the lung local infectious inflammation will take place, except when there is the fortunate combination of low virulence and extraordinary resistance of the system. When the embolic material was sterile, no inflammatory process followed.

I wish to remind you of a patient who had been operated on for varicose veins, and who during after-treatment experienced, with alarming swiftness, partial embolism of the lung. If there had been phlebitis, one would have had to fear gangrene with abscess of the lung; if not, the size of the embolism would decide recovery or rapid fatal issue.

The important question of the usefulness of ligation of the pulmonary artery and its branches in the treatment of patients with pulmonary infections was briefly touched on. In animal experimentation one never sees gangrene of the lung or abscess after such a ligation so long as the work is carried out aseptically. This was observed in the clinic. One must remember that the pulmonary artery is a functional, not a nourishing, blood vessel, carrying the blood to the alveoli for the exchange of gases. If the pulmonary artery is ligated, the bronchial arteries continue to attend to nourishment of the tissue of the lung. There is no reason why local gangrene should occur so long as perfect asepsis is maintained. In the consideration of this chapter of thoracic surgery it is wise to remember that anastomoses exist between the bronchial arteries and the branches of the pulmonary artery.

The question was stressed whether an abscess of the lung is caused by embolism or by aspiration. I think all of us who have given the question due consideration and observation have come to the conclusion that opposing minds have to compromise. We have to say that both, embolism as well as aspiration, may be the cause. The main point is: What is the percentage of each? This question was raised particularly in New York about ten or fifteen years ago, when a real epidemic of abscesses of the lung was seen following the many tonsillectomies done in the early study of the cure of the so-called focal infections. There was a great number of cases of acute pulmonary infections, and a cry went up from the medical profession, particularly in discussions at the Academy of Medicine, that something was wrong in the method of removing the tonsils. The specialists working in this line quickly took this to heart. Today I can state conscientiously that abscess of the lung following tonsillectomy is a rarity in New York. Why? Because the physicians who do not operate under local anesthesia employ experts for the general anesthesia, who handle electric suction of the fauces to perfection. Can there be a better proof for the claim, that "aspiration" has been the principal factor in the occurrence of abscess of the lung after the removal of the tonsils? I know of one colleague standing high in the medical profession who has had only one case following tonsillectomy in the last fifteen years in the wards of a big hospital. He was so mortified that he personally went to the hospital day and night to see how the patient was getting along.

There is, then, no question but that operations on the tonsils, operations within the mouth, nose and pharynx are the cause of the greatest majority of post-operative abscesses of the lung, and their formation must be principally due to the aspiration in the course of the operation.

Just one word on bronchoscopy, which has come to the fore in this group of cases. Personally, I have always considered bronchoscopy equal to cystoscopy in the diagnosis and treatment of diseases of the urinary system. We all have hailed with delight the use of the ophthalmoscope, the pharyngoscope, the cystoscope and now of the bronchoscope. I believe that we owe it to our thoracic patients with expectoration, to subject them to bronchoscopy, so long as there is no valid contraindication. What an expert sees with his eyes, he sees; his diagnosis stands. Knowing that aspiration of a foreign body so frequently is the cause of suppurating pneumonitis, this fact alone demands the use of the bronchoscope. To my mind it is necessary that every well conducted hospital has a trained bronchoscopist in whose diagnosis the other colleagues can trust.

Suppuration of the lung is also due to cancer. If we take the stand that every case of unexplained persistent cough should be cleared up, if possible, we should insist on having bronchoscopy done on such a patient as soon as possible. Cancer of the lung is most frequently seen in the right main bronchus. Dr. Jackson of Philadelphia treated some patients with this condition years ago. Dr. Kernan, the bronchoscopist of the Lenox Hill Hospital in New York, now has under observation two early cases of cancer of the lung which started in the main bronchus. One case has been cured by local treatment through the bronchoscope; the other is still under observation. I believe that at least nine tenths of the cases of cancer of the lung originated in one of the main bronchi, and that in the majority of these cases, always fatal in former years, there is a good chance of cure being obtained if diagnosis is made early and treatment given locally through the bronchoscope.

Dr. Howard Lilienthal, New York: Solon has said that we must not count any man happy until he is dead, because no one can say what misfortune may happen to him before that time.

Let me call attention to the fact that people with abscesses of the lung are not well merely because they leave the hospital after recovery from operation. In estimating statistics presented here today we must remember that those statistics have to be taken with many allowances; not on account of intentional misrepresentation, but because one cannot tell what is going to happen to a man who has an abscess of the lung and leaves the hospital improved but not normal as, for example, with bronchial fistula. He may be able to work, as it was shown in one or two of the tables, and he is apparently well, except that he has a bronchial fistula. But no one can tell what the final result may be. Many will die of hemorrhages, recurrence of abscess or gangrene or of other septic processes which develop afterward as a result of the bronchial fistula.

Bronchial fistula is only one of the complications I shall mention, because there is not time to go into the discussion of them. I wish to call attention, then, to the fact that in estimating the improvement, including the ability to work, we should count only those persons really cured who have intact chest walls, and in whom the process that led to the abscess of the lung has been eliminated. Those patients who were discharged from the hospital as improved should not be considered well statistically until a long period of time has passed. I have seen deaths occur four, and even five years after the establishment of bronchial fistula, the usual causes being hemorrhage or recurrent pulmonary gangrene and its consequences.

Dr. Wyman Whittemore, Boston: I wish to speak for just a minute on Dr. Scrimger's paper.

Two years ago, at the meeting of the American Surgical Association in Richmond, Dr. Eugene Doble showed some lantern slides of a case much like Dr. Scrimger's. He had filled an abscess cavity with muscle flaps, and the patient made a perfect recovery. Patients with chronic abscess of the lung who have been operated on and who have left the hospital with a fistula have been of special interest to me for a long time. Many of these patients do not do well in that the fistulas never heal.

Following Dr. Doble's method, I have operated on five such patients. Some of them had been operated on several times previously; one had had a cautery excision done. One such patient was operated on in Boston last fall before the American College of Surgeons. It was interesting to me to see that a very large cavity such as this one could be completely filled and closed with muscle flap. In all five cases the wound healed solidly and promptly, in about two months. Three of the five patients are well and have no symptoms and raise no sputum;

one patient still expectorates a small amount of sputum but looks well and has gained 30 pounds in weight. Another patient who cannot be considered cured is a woman who had a large cavity from which she had occasional hemorrhages. I operated on her last fall, and closed the abscess cavity with muscle flap. She has done very well, except that she has had one or two small upsets with a little bloody sputum, but these upsets have quieted down while she has been kept in bed.

DR. GEORGE P. MULLER, Philadelphia: My experience has been similar to that of Dr. Flick and his associates, particularly as we have the same close association with the internist, roentgenologist and bronchoscopist. During a period of six years, thirty-five patients with abscesses of the lungs were referred to me for operation. There were ten deaths (28.6 per cent). I want to bring out the point that age makes a material difference in the risk of an operation. The average age of these patients was 36 years, and the mortality of operation in those over 36 years was 44 per cent, whereas in the group below 36 years it was 16 per cent. In eight patients over 50 years of age, the mortality was 62.5 per cent. The mortality in the post-tonsillectomy group was considerably less than in the other, but the average age of these patients was 15 years less than of the other.

A second point concerns the end-results. A number of patients discharged as cured or improved have a relapse and die. In a group of twenty-five patients followed up for at least one year, the final mortality was 40 per cent. Again note the age factor. In the cases in which cure was obtained (at least one year follow-up) the average age of the patient was 32 years, whereas among those who died or improved only, the average was 45 years. Abscess of the lung is a serious disease and only a long follow-up period shows how serious it is.

DR. A. L. LOCKWOOD, Toronto, Canada: I think all of us will concede that operations of all kinds on the nose and throat should be done under local anesthesia. It ought to be the duty of every one of us here to speak continually concerning this to physicians in general, and particularly to internists and the nose and throat specialists. In traveling around the country, one notices that these specialists are still employing general anesthetics in certain cases. They do not want to bother with the nervous, irritable type of girl of about 16 or 17, so they give a general anesthetic. I do not think that the medical profession is entirely cognizant of the incidence of abscess of the lung following operations on the nose and throat done under general anesthetics.

There is one other point, and that is the question of treatment. I do not believe that we ought to be too hurried in the use of the bronchoscope or any radical measure for the treatment of abscess of the lung. Experience has shown us that at least half of these patients are probably cured by postural drainage. If they do not show benefit and improvement under postural drainage, the use of the bronchoscope is indicated.

I would not attempt to argue with the bronchoscopist. We employ him constantly. At the same time, a bronchoscopic examination is not altogether a simple matter. I would much rather have a cystoscopic than a bronchoscopic examination.

Dr. Harrington has just brought up a point. He has realized that surgical intervention should not be attempted for at least two weeks after the bronchoscopic examination. I believe that would be the experience of most of us who have operated in many of these cases after bronchoscopic examination. We make it a rule not to do any surgical work until from ten to fourteen days after a bronchoscopic examination.

If the patient is not improved with postural drainage, and with clearing up of all foci of infection, we should do a bronchoscopic examination as a routine.

If the abscess tends to drain following that one examination, we ought to carry on again without the bronchoscopic treatment. We should depend on postural drainage, and use bronchoscopic treatment only when the patients are not benefited by postural treatment.

If these patients are not holding their own, and are not improving with bronchoscopic treatment, we should not delay the surgical treatment too long, but stop the bronchoscopic treatment before bronchiectasis develops, which too frequently occurs after some months.

When it comes to the question of radical surgical intervention, I think that we have to be extremely radical, but that we must use multiple step operations, not doing too much at one time, yet uncovering the cavities widely.

I agree with a previous speaker in regard to tube drainage. I think the abscess cavity should be packed with gauze, fairly firmly, so that there will be some pressure against the open bronchioles, enabling the rest of the lung to be cleared by coughing.

As regards the question of muscle flaps, I do not believe that is altogether a new idea, although it may be a new method of putting them in. They have been tried over some period. If bronchial fistulas are present, I do not believe 100 per cent would be cured by muscle flaps. A muscle flap should not be used over an open bronchial fistula, unless the fistula is exposed and the flap placed adjacent to it. It is necessary to mobilize the cavity so as to allow a collapse about the fistula. After the fistula is closed, muscle flaps should be employed.

Dr. Ethan F. Butler, Elmira, N. Y.: Postoperative pulmonary suppuration may be either of embolic etiology or due to aspiration. Dr. Van Allen has indicated the importance of considering a dual etiology.

Prevention of such conditions or the abortion of an impending condition will always be better than a cure. Prevention of suppuration of embolic origin must necessarily depend on the operator's surgical technic. Prevention of suppuration due to aspiration will depend partly on oral hygiene and partly on the ability of the patient to remove infected secretions from the bronchial tree. Therein I believe postoperative hyperventilation by carbon dioxide is of definite value. Increased respiratory effort will clear secretions from the bronchi.

During the past seven years I have seen many patients who, following upper abdominal operations, have been either unwilling or unble to cough up thick tenacious secretions. Within one, two or three days after operation there has been a clinical picture of severe purulent bronchitis, even of impending pneumonia. In ten or a dozen such cases, the purulent secretions have been removed by bronchoscopic methods, and immediately gratifying results have been obtained. The patients have become relieved from distressing symptoms. The temperatures have dropped, and there has been no reaccumulation of secretions with which the patients have been unable to cope. In no case has harm resulted to the recent wound or to the patient.

Dr. Elliott Carr Cutler, Cleveland: Dr. Willy Meyer and Dr. Butler have both emphasized that it is time the proponents of the aspiration and embolic theories tried to get together. I heartily agree with this.

There may be those who think we have overemphasized the embolic theory. We have done this because few paid much attention to the dangers of embolism and seemed to want to blame the anesthetists for their postoperative sequelae, which we felt was unjust.

Dr. Van Allen has just presented a brilliant piece of work. For some time we have tried to superinfect bland emboli by mouth aspiration, in an attempt to correlate both the aspiratory and embolic theories. It was hoped that by freeing

bland emboli which would cause infarction we might then infect these areas from above by mouth organisms. We failed to do this, though Dr. Van Allen has now succeeded.

In his discussion, I wish Dr. Van Allen would point out the type of organisms that were injected in the later contaminations, whether they were pushed down by the bronchoscope or were insufflated, and whether the time interval was a very important factor. If one creates an infarct in the lung or an abscess by the embolic method, these lesions early in their course are not connected with the bronchus. It is difficult for me to imagine exactly how aspirated material gets into the walled-off space and results in chronic abscess. We have no definite criteria to go on.

One insufflation of various types of organisms, whether mouth anaerobes or not, does not usually produce an abscess of the lung, though it is a simple matter to produce abscess of the lung by an infected embolus. Yet we are continually finding that in abscesses of the lung there are many mouth anaerobes. One would like to put these observations together. Experimental abscess is easily created by using emboli infected with mouth anaerobes. Possibly a lightly infected embolus from the operative wound enters the lung and devitalizes the tissue both by reason of the bacteria and the loss of blood supply. When mouth anaerobes are inspirated into this area, a chronic abscess is produced.

Although we have failed to do this experimentally, we have observed this sequence of events in clinical cases and utilized this theory for its prognostic value.

Within a year, a patient, aged 27, weighing 200 pounds (90.7 Kg.), was operated on for gallstones. Within two weeks a localized lesion with a fluid level, obviously an abscess, was demonstrated. Also, in a case of ligation of the jugular vein for lateral sinus thrombosis, we observed two abscesses in different lobes within four weeks of operation. The examination showed small, walled-off abscesses with fluid levels. These abscesses were from 3 to 5 cm. in diameter and well walled-off. Both patients had very clean mouths, with only occasional spirochetes. They were given arsenic from the beginning, and we predicted that these lesions would heal promptly if secondary invasion with mouth organisms did not occur; exactly this occurred.

From these observations and from Dr. Van Allen's experiments I think one can predict that small pulmonary abscesses, if the mouth is kept clean and the mouth organisms controlled by arsenic, will not go on to the chronic stage. This would seem to be the practical value of all the experimental work thus far presented.

I do believe that in a great many abscesses, particularly chronic ones, both embolism and aspiration are the causative factors, the aspiration being secondary to the embolus and establishing the chronicity of the lesion.

Dr. Kennon Dunham, Cincinnati: We have heard a good deal this morning about the bronchoscopic treatment of abscess of the lung. Personally, I should like to know a little more about it. What is the purpose of bronchoscopic treatment of the lung? Is it the aspiration of pus, or is it the washing of the lung as has been recommended in cases of bronchiectasis? I should like to know a little more of what is done with the bronchoscope.

Dr. F. A. C. Scrimger, Montreal, Canada: I wish to make only one remark. Strictly speaking, it is not a flap that is used, but rather a plug of the muscle in the bronchus. I think that is recognized.

Dr. John B. Flick, Philadelphia: In reply to Dr. Lillienthal's comment, I should like to say that the patients classified as having made "complete recoveries"

have been followed up, and most of them have been heard from within the last two months. The wounds were completely closed, and the patients were free from symptoms.

Of the group of twenty-nine patients treated by external drainage, three were classified as having "recovered with bronchial fistulas." In two of these cases it was a question of either doing an extensive operation or permitting the bronchial fistulas to remain. The three patients when heard from were actively engaged in work; one as a gardener, one as a salesman and the third at school.

In our experience closure of fistulas is best accomplished by excising the old scar, undermining the soft tissues, again exposing widely the diseased area and cauterizing it thoroughly. The fistulas may then at once close with the healing of the wound, or this procedure may have to be repeated a number of times.

Dr. Louis H. Clerf, Philadelphia: Answering Dr. Dunham's question, bronchoscopic treatment in pulmonary abscess consists primarily in the removal of pus and the improving of drainage; in those cases in which the abscess does not communicate with a bronchus no attempt is made to create a communication, although this is probably mechanically possible. Irrigation is rarely used in these cases; dependence is placed on aspiration with the aid of rigid or flexible, curved or straight aspirating tubes introduced through the bronchoscope into the bronchus draining the abscess.

Dr. Butler's cases recall to mind similar cases referred to us by Dr. W. E. Lee; in these we believe there was atelectasis of the lung. By bronchoscopy, a considerable quantity of thick, tenacious secretion was removed.

Bronchoscopy should be used early in the treatment of patients with abscess of the lung. It is, of course, a question whether it should be performed on acutely ill, septic patients who have diffuse pneumonitis. Skilfully performed bronchoscopy can be considered safe for all practical purposes. Because of this, I know of no sound reason for delaying bronchoscopy to see what will happen to the patient. The frequently observed remarkable improvement following one or two bronchoscopic aspirations in very ill patients is sufficient justification to warrant this assumption.

I agree with Dr. Lilienthal's reference to statistics. Medical statisticians are said to have little regard for the facts. We have tried hard to be fair with ourselves and with those who read these statistics. In so doing we have accepted the only method of expressing our results.

Dr. C. M. Van Allen, Chicago: In reply to the kind remarks of Dr. Cutler, I may say that three different sputums were used for inoculation in these experiments; one contained many spirochetes of Vincent, the second, *Fungus nocardia*, which organism is capable of producing extremely chronic suppurative lesions in man, and the third nonspecific, pyogenic bacteria. The ordinary cultural methods and stains were employed in identifying the organisms.

The reason why we succeeded in lengthening the healing time of abscess of the lung by intrabronchial inoculation, whereas Dr. Cutler's associates failed, was probably the one he has given, i. e., that we waited until the tenth day to superinoculate, when the abscess had reached its maximum size and acquired bronchial communication. Such communication would appear to be a necessary factor. There is no other way that I can see for these organisms to reach the abscess.

We believe that superinoculation of the bronchial tree and associated ulcerative lesions of the lungs occurs more frequently than is commonly supposed. A considerable mass of clinical and experimental evidence to support this belief exists and is not generally taken into consideration. For instance, Iglauer, examined the lower respiratory tract for blood after tonsillectomy performed under local anes-

thesia and found contamination in 75 per cent of his cases. Ochsner noted the same thing. He also gave patients who had received procaine hydrochloride anesthesia in preparation for tonsillectomy a few cubic centimeters of iodized oil to swallow, and found that the oil was aspirated in every case. Thus, in using local anesthesia we are not avoiding contamination of the lower respiratory tract in operations on the throat. Moreover, the ease with which any bland fluid accumulating in the unanesthetized pharynx overflows into the larynx and reaches the bronchi is strikingly illustrated by the method of Dr. Singer for intrabronchial introduction of iodized oil. Mucus or mucopus, gathering in the throat during sleep or other time when swallowing is not often engaged in, probably frequently contaminates the trachea and bronchi.

This frequency of bronchial contamination makes the bronchogenic theory of origin of abscess of the lung difficult to understand, without assuming that another factor of lowered resistance plays an essential rôle. And the lowered resistance factor must be a specific circumstance not fully understood, for the usual general and local resistance cannot explain the facts. Thus, the type of patient, above others, in which abscess of the lung is seen is the comparatively well and young person undergoing tonsillectomy; whereas, in operations on the skull, as Dr. Cutler has pointed out, the minimum of postoperative complications of the lungs occurs, although the patients lie under general anesthesia for hours with lowered reflexes and a seriously depressed physical state. What specific circumstance it is of lowered resistance of the lung that prepares it for the intrabronchial inoculation and abscess formation we cannot say further than to suggest that ischemia of a sector of the lung from embolism may be the factor. These experiments show that parenchyma of the lung devoid of its blood supply in large part by an embolus becomes more susceptible to bronchogenic contamination than the normal lung.

DR. EMILE HOLMAN, San Francisco: We too have been investigating the lymphatics of the lung. We find that the injection of the lymphatics over the surface of the lung shows that they lead down directly through the lung tissue to the deeper areas along vessels and bronchus. It is possible that the embolized area may become infected through the lymphatics which drain the bronchus.

POSTOPERATIVE PULMONARY HYPOVENTILATION *

GEORGE P. MULLER, M.D.

RICHARD H. OVERHOLT, M.D.

AND

EUGENE P. PENDERGRASS, M.D.

PHILADELPHIA

The consideration of postoperative pulmonary conditions is of necessity an important one. The fulminant course or the protracted convalescence that follows after such complications forces the question into a major position.

This problem has been approached by many writers (Shultz,[1] Cutler,[2] Cleveland,[3] etc.) after they have gone over large numbers of hospital records and studied the cases listed under pulmonary complications. Carefully planned clinical studies directed toward this condition have been carried out by Whipple[4] and Elwyn.[5] Results of these various investigations have helped to clarify the problem in regard to many of the contributing factors in the production of postoperative pulmonary complications. The influence of preexisting pathologic changes, the seasonal variation and the relation of epidemics of infections of the upper respiratory tract to pulmonary complications have been commented on by Ravdin and Kern.[6] For a long time "ether pneumonia" and the effect of the type and duration of the anesthetic occupied an important place in the literature and was discussed by Robb and Dittrick,[7] Whipple,[4] Decker[8] and others. The importance of direct irritation of the pul-

* From the Departments of Surgery and Roentgenology in the Hospital of the University of Pennsylvania.

1. Shultz: Medical and Surgical Reports of the Presbyterian Hospital, New York, January, 1898.

2. Cutler, E. C., and Morton, J. J.: Postoperative Pulmonary Complications, Surg. Gynec. Obst. **25**:621 (Dec.) 1917.

3. Cleveland, Mather: Further Studies in Postoperative Pneumonitis, Surg. Gynec. Obst. **27**:282 (March) 1919.

4. Whipple, A. O.: A Study of Postoperative Pneumonitis, Surg. Gynec. Obst. **26**:29 (Jan.) 1918.

5. Elwyn, H.: Postoperative Pneumonia, J. A. M. A. **82**:384 (Feb. 2) 1924.

6. Ravdin, I. S., and Kern, R. A.: Pulmonary Complications Following Anesthesia and Operation, Arch. Surg. **13**:120 (July) 1926.

7. Robb, H., and Dittrick, H.: Pulmonary Complications Following Abdominal Operations, Surg. Gynec. Obst. **3**:51 (July) 1906.

8. Decker, H. Ryerson: Postoperative Complications of the Respiratory Tract, Penn. M. J. **24**:391 (March) 1921.

monary epithelium and the relation of aspiration to subsequent pulmonary infection has been considered by Bevan,[9] Herb [10] and Myerson.[11]

During the past decade the authors writing on postoperative pulmonary complications could be subdivided into three groups, namely, those emphasizing the importance of emboli; those who hold that most complications are due to a pneumonitis, and those who emphasize the frequency of massive or lobular atelectasis resulting from bronchial obstruction.

Cutler and Morton,[2] in an extensive review of cases, came to the conclusion that embolism was important in the production of postoperative pneumonia. They pointed out the various factors favoring the formation of emboli, such as the presence of septic foci, infection in the operative site, and vessel access to the lungs. They also emphasized the tendency to pulmonary hypostasis resulting from poor expansion due to reflex splinting of the abdomen. Later, Cutler [12] restated his views regarding the embolic theory and substantiated his opinion with roentgenographic studies.

That most of the forms of pulmonary complications are due to a diffuse inflammatory process or pneumonitis has been maintained chiefly by Whipple.[4] He considered most of the temporary postoperative "reactions" indicative of a mild pulmonary complication and the extension of an acute infection of the upper respiratory tract as the exciting cause. The pathologic change consists principally of vascular congestion and edema with little exudation, and the type IV pneumococcus is the chief organism found. The roentgenograms show a diffuse mottling most marked at the bases, principally the right. This complication occurred in 2.6 per cent of all operative cases in the large series collected by Whipple. Cleveland [3] reported a higher percentage of pneumonitis, 33 per cent.

During the past few years, the literature on embolic pneumonia and postoperative pneumonitis has given way to a veritable flood of papers on pulmonary collapse or atelectasis. Although Joerg, as early as 1832,[13] and Gairdner, in 1851,[14] gave accurate clinical and pathologic

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9. Bevan, A. D.: The Choice and the Technic of the Anesthetic, Tr. Am. Surg. **33**:21, 1915.

10. Herb, I. C.: Ether: Simplicity in Its Administration, J. A. M. A. **66**: 1376 (April 29) 1916.

11. Myerson, M. C.: Bronchoscopic Observations on the Cough Reflex in Tonsillectomy Under General Anesthesia, Laryngoscope **34**:63 (Jan.) 1924.

12. Cutler, E. C.: The Etiology of Postoperative Pulmonary Complications, Surg. Bull. N. Amer. **2**:935, 1922.

13. Joerg, E.: Researches on Solidification of the Lungs in New-Born Infants, Dublin J. M. Sc. **5**:36, 1834.

14. Gairdner, William T.: On the Pathological Status of the Lung Connected with Bronchitis and Bronchial Obstruction, Month. J. M. Sc. **11**:122, 1850; **12**:440, 1851; **13**:238, 1852.

descriptions of atelectasis, it was not until the term was revived by Pasteur,[15] Bradford[16] and Scrimger[17] that such a condition was considered in writings on postoperative pulmonary complications. After having recognized atelectatic states in which entire lobes were involved (massive atelectasis), Mastics[18] and his co-workers and Lee and Tucker[19] recently described a patchy or lobular collapse. The occurrence of this type of pulmonary complication after an abdominal operation is even more frequent, according to these reports, than the embolic processes of Cutler or the cases of postoperative pneumonitis of Whipple. Boland and Sheret[20] reported 30 cases in a series of 261, an incidence of 11.5 per cent. Mastics and his co-workers[18] concluded that lobular atelectasis comprises 70 per cent of all pulmonary complications.

My associates and I have been engaged in a study of the pulmonary observations of patients before and after upper abdominal operations, and a number of interesting observations have been made. This clinical study was undertaken because the following phases of the subject seemed to need clarification:

1. The frequency of positive reports from the roentgenologic department in patients examined postoperatively in which the subsequent course of events indicated that a pulmonary complication did not exist.

2. The confusion and interchange of terms, such as postoperative pneumonitis, bronchopneumonia, lobular atelectasis, massive atelectasis, "lung reaction," or infarct, these terms being used in describing postoperative pulmonary complications.

3. The marked reduction in vital capacity which was reported by Churchill and McNeil,[21] and Powers[22] following upper abdominal operation.

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15. Pasteur, W.: The Causation of Postoperative Massive Collapse of the Lung, Lancet **1**:1428, 1914.

16. Bradford, J. R.: Massive Collapse of the Lung, Oxford System of Medicine, 1918-1919, vol. 12, p. 122.

17. Scrimger, F. A.: Postoperative Massive Collapse of the Lung, Surg. Gynec. Obst. **32**:486, 1921.

18. Mastics, E. A.; Spittler, F. A., and McNamee, E. P.: Postoperative Pulmonary Atelectasis, Arch. Surg. **15**:155 (Aug.) 1927.

19. Lee, W. E., and Tucker, G.: Postoperative Pulmonary Atelectasis, Atlantic M. J. **31**:284 (Feb.) 1928.

20. Boland, C. R., and Sheret, J. R.: Postoperative Massive Collapse, Lancet **2**:111 (July) 1928.

21. Churchill, E. D., and McNeil, D.: The Reduction in Vital Capacity Following Operation, Surg. Gynec. Obst. **44**:483, 1927.

22. Powers, John H.: Vital Capacity; Its Significance in Relation to Postoperative Pulmonary Complications, Arch. Surg. **17**:304 (Aug.) 1928.

4. The limitation of diaphragmatic function as reported by Sise [23] and its relation to the reductions in vital capacity.

5. The presence of preexisting pulmonary pathologic change and its effect on diaphragmatic limitation.

METHODS

Twenty-five cases in which upper abdominal operations were to be performed were studied. No selection of cases as to operative risk, general appearance, etc., was made. None of the patients had any deformity of the chest or gross pulmonary pathologic changes. Cases in which ascites was present were not used. Care was taken that not more than two or three patients were under observation at the same time in order that ample time might be spent in the study of each patient before and after operation.

Daily notes were kept in regard to progress of pulmonary symptoms and physical signs. After operation, the examinations of the chest were made as thoroughly as the condition of the patient permitted. We were able in all cases to examine the bases posteriorly by carefully turning the patients on one side and then on the other.

Measurements of the circumference and expansion of the chest were made before operation and at intervals of two days after operation. The tip of the xiphoid process and the third interspace in the midclavicular line were selected for fixed points for measurement.

Determinations of vital capacity were likewise made before, and at intervals after, operation. The ordinary clinical spirometer was used. The highest of three trials was the vital capacity recorded in each instance.

The patients were studied fluoroscopically in the recumbent and erect postures by the central ray method. The diaphragmatic movements were recorded during quiet (tidal) breathing and during the maximal respiratory phases (deep breathing). The positions of the domes of the diaphragm were marked directly on the fluoroscopic screen with a wax pencil, and these tracings were then transferred to cards for a permanent record. After operation various methods of roentgenoscopy were tried, but the most workable plan and the one which caused the least discomfort to the patients was simply to lift them from their beds to the adjustable fluoroscopic table. With adequate help most patients had practically no pain, and none of the twenty-five, at the time of the examination or later, showed evidences of injury from such a procedure.

Preoperative roentgenograms were made as a routine. After the first four cases were studied it became obvious that the preoperative

23. Sise, L. F.; Mason, R. L., and Bogan, I. K.: Prophylaxis of Postoperative Pneumonia, Anesth. & Analg. **7**:187 (May-June) 1928.

roentgenogram should be taken in bed in order that this record would be of value in comparing it with the postoperative examinations. In half of the cases studied, roentgenograms were made during the expiratory phase, as well as during the inspiratory phase. In some of the cases in which this study was not made the day before operation, we used for comparison roentgenograms made when the patient returned three months later for follow-up examination. Great care was taken by the technicians to make all exposures with the patients in as near the same semi-Fowler position in bed. Lateral roentgenograms were made in more than half the studies.

RESULTS

The preoperative examination of the patients, from both the clinical and the roentgenologic standpoints, revealed little preexisting pathologic change. However, the importance of the preoperative roentgenograms

TABLE 1.—*Type of Cases Studied*

Operation	Number of Cases	Convalescence Prolonged on Account of Pulmonary Complications	Suspicious Clinical Course	Positive Roentgenograms *
Biliary tract	12	0	2	9
Gastric	11	1	1	8
Epigastric hernia	1	0	0	1
Splenectomy	1	0	0	1
Totals	25	1	3	19

* The conditions reported as showing positive roentgenograms were postoperative pneumonitis, bronchopneumonia, lobular atelectasis, massive atelectasis and pulmonary infarct.

when used for comparative purposes with postoperative studies soon became evident. In one case an obliteration of the costophrenic angle due to pleural adhesions was found, which, without the preoperative studies for comparison, might have been interpreted as postoperative pathologic change. We were unable to predict from the preoperative examination of the chest which patients would develop pulmonary complications after operation.

In this series, the operations performed included principally those on the stomach or biliary tract (table 1). The postoperative course was prolonged in one case, this being due to bronchopneumonia. There were no deaths due to a pulmonary complication in the series of cases studied.

The symptoms which suggested a pulmonary complication were few (table 2). Dyspnea and cough were present in only three cases. Hemoptysis of slight amount was reported by one patient. It was in this case that the appearance on the roentgenograms suggested an infarct, and subsequently bronchopneumonia developed on the sixth postoperative day.

Positive physical signs were found surprisingly often in a greater number of these cases than the paucity of symptoms would indicate (table 2). Diminished expansion, especially of the bases, was evident by gross inspection in all of the patients. In four of five patients, suppressed or absent breath sounds were noted over the lower lobes. The diminution in the transmission of sounds was most noticeable at the right base posteriorly. In five of the twenty-five cases, tubular breathing was heard at some time during the postoperative course. Over the same areas, whispered and spoken voice sounds could be heard. These areas over which there was increased transmission of sounds were irreg-

TABLE 2.—*Pulmonary Symptoms and Positive Physical Signs*

After Upper Abdominal Operations, 25 Cases	Number of Cases	Per Cent
Dyspnea	3	12
Cough	3	12
Expectoration	2	8
Hemoptysis	1	4
Chest pain	0	0
Positive Physical Signs		
Cyanosis	2	8
Diminished expansion	25	100
Diminished resonance	8	32
Suppressed or absent breath sounds at bases	20	80
Tubular breathing	5	20
Râles	14	56

TABLE 3.—*Measurements of the Chest* *

	Circumference at Xiphoid Process	Expansion	Circumference at Third Interspace	Expansion
Before operation	79.2 cm.	6 cm.	84 cm.	5.8 cm.
After operation	82	1.3	86.7	1.8
Increased circumference	+2.8 cm.		+2.7 cm.	
Decreased expansion		—4.7 cm.		—4.0 cm.

* This table shows the average changes in measurements of the chest in fifteen of the cases studied before and twenty-four hours after operation. The marked reduction in chest expansion at both points of measurement should be noted.

ular in outline and did not usually appear during the first twenty-four hours after operation, but were elicited thirty-six or forty-eight hours later. Râles were heard in fourteen of the twenty-five patients and were most marked at the bases. The positive physical signs, such as diminished resonance, pectoriloquy and tubular breathing, were evanescent and disappeared in from twenty-four to seventy-two hours as the vital capacity increased.

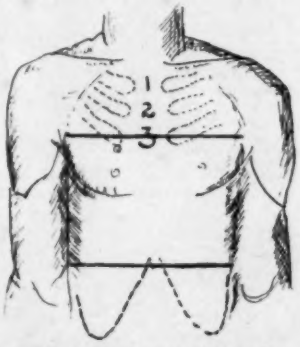
Measurements of the chest after operation in fifteen of the cases showed a marked reduction in the expansion. The average expansion of 6 cm. as measured at the tip of the xiphoid process before operation averaged only 1.3 cm. during the first twenty-four hours after operation (table 3). A similar diminution of expansion was found when the

measurements were taken at a level of the third interspace. The preoperative average expansion was 5.8 cm., and the day following operation it was found to be only 1.8 cm. The measurements of circumference of the chest showed an increase following operation, the average being 2.8 and 2.7 cm. in the two locations in which the measurements were taken. In figure 1 is illustrated graphically the average alterations in expansion and circumference of the chest as recorded before and at intervals after operation. In table 4 is shown the record in one of the cases. This was selected as showing the typical enlargement of the circumference of the chest immediately following operation and the return to normal size as the convalescent time advanced and the expansion increased.

In only one case in this series was the postoperative circumference of the chest noted to be less than it was in the preoperative record. Mea-

TABLE 4.—*Change in Chest Measurements Before and at Intervals After Operation in Case 16 (J. D.)**

		Circum. at Xiph.Proc.	Expansion	Circum. at 3rd Interesp.	Expansion
PRE-OP.		82 cms.	10	86	11
POST-OP.	1	85	2	89	3.5
DAYS	3	84	5	87	6
	5	84	5	87	6
	7	84	4.5	86	8
	9	81	7	86	8



* The return to normal circumference and expansion as the convalescent time advanced should be noted. Circumference measurement taken after full expiration. The figure illustrates fixed points selected for making measurements. The patient was a glass blower on whom a gastro-enterostomy was performed.

surements were made in two patients with ascites (not included in this series) on whom a Talma operation was done. In these cases the circumference of the chest was less after operation.

The vital capacity of this group of patients averaged 2,918 cc., which is 75 per cent of the average normal for these patients as calculated by West's[24] formula (2.5 liters per square meter surface area for men and 2 liters per square meter for women). On the first postoperative day the average vital capacity was only 33 per cent of the preoperative reading, and the recovery was gradual. Readings taken every second day showed an improvement, so that on the eleventh postoperative day

24. West, H. F.: Clinical Studies on Respiration; Comparison of Various Standards for Normal Vital Capacity of Lungs, Arch. Int. Med. **25**:305 (March) 1920.

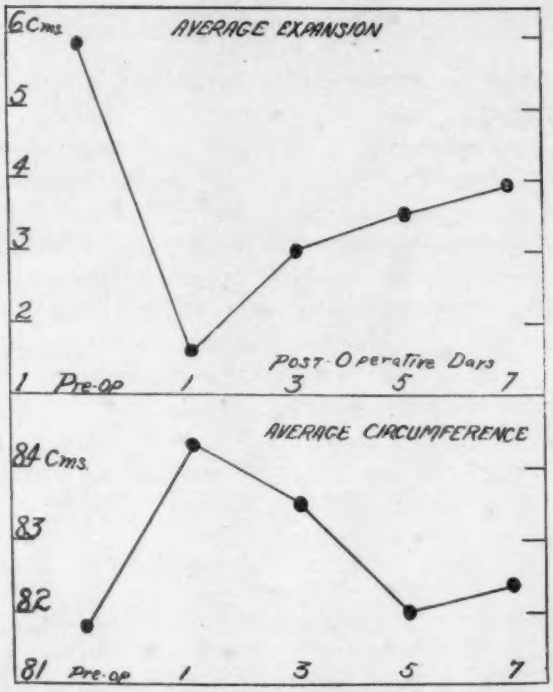


Fig. 1.—Graph showing decrease in the expansion of the chest in fifteen cases after upper abdominal operation. Recovery was gradual and responded to improvement in vital capacity. The increase in the circumference of the chest during full expiration should be noted. Measurements were made at the third interspace and the xiphoid process. A metal tape measure was used.

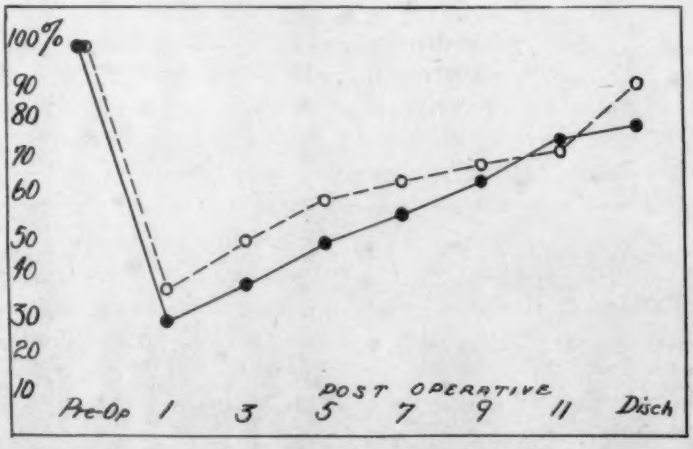


Fig. 2.—Graph showing reduction in vital capacity after upper abdominal operations. Little difference was noted in the average vital capacity records of the six patients in whom the postoperative roentgenograms were clear and in those nineteen cases showing changes postoperatively on the roentgenograms. The solid lines indicate positive roentgenograms and the dotted lines, negative.

an average of 78 per cent of the normal vital capacity was obtained. At the time of discharge, 80 per cent of the normal vital capacity for these patients was the average record. In figure 2 is shown the reduction in the cases, grouped as to whether or not they had positive roentgenologic reports. The significance of these reports is commented on elsewhere in the text. Of the three patients in the group who had frank pulmonary complications, the vital capacity curves were abnormal in two. In one patient (L. M. in table 6) with a complete collapse of the right lung, an average postoperative vital capacity curve was obtained. The maximum fall was 77 per cent, and the recovery was progressively upward. The other two patients (H. W. and F. W., table 6) had the usual initial drop, but the recovery was slow and on the eleventh postoperative day the reading was only 40 and 51 per cent, respectively, of the preoperative record.

TABLE 5.—*Diaphragmatic Excursions Before and After Upper Abdominal Operations in Twenty-Five Cases* *

	Fullest Expiration and Inspiration (Maximal)			
	Right		Left	
	Erect	Recumbent	Erect	Recumbent
Before operation	3.4 cm.	5.32 cm.	3.8 cm.	5.48 cm.
After operation	1.17	1.6	1.74	1.0
	Quiet Breathing (Tidal)			
Before operation	1.02	1.24	0.99	1.27
After operation	0.6	0.65	0.79	0.7

* In this table, measurements were made fluoroscopically under uniform conditions before and twenty-four hours after operation.

At the roentgenoscopic examination, an elevation of the domes of the diaphragm was observed in all of the cases after operation. The elevation was most marked on the right side and especially so in two patients in whom later an early massive atelectasis proved to be present. Comparisons in height of the domes of the diaphragms were made from the bedside films. Measurements were made of the perpendicular line dropped from the transverse process of the first thoracic vertebra to a horizontal line through the dome of the diaphragm on each side. The average measurement of the right perpendicular before operation was 25.8 cm. and after, 21 cm., leaving a difference of 4.8 cm., which represents the elevation of the diaphragm after operation. On the left side the perpendicular measurement was 26.5 before and 23 cm. after operation, showing that its position was lower than the right dome and its elevation slightly less (fig. 3).

Diaphragmatic movements before operation were unrestricted in all cases. The maximal excursions were found in the recumbent positions, during both forced and quiet breathing (table 5). It can be seen from this table that in both positions the maximum excursion of the diaphragm

was reduced after operation to a third of its preoperative range of movement. The tidal fluctuations were diminished about one half.

It was also observed that the position of the tidal fluctuation of the diaphragm varied in regard to its position in the maximum range of excursion. Before operation, the tidal movements took place in the lower third of the possible range noted during forced breathing. However, after operation the tidal fluctuations occurred in the upper third of the possible range of movement of the diaphragm.

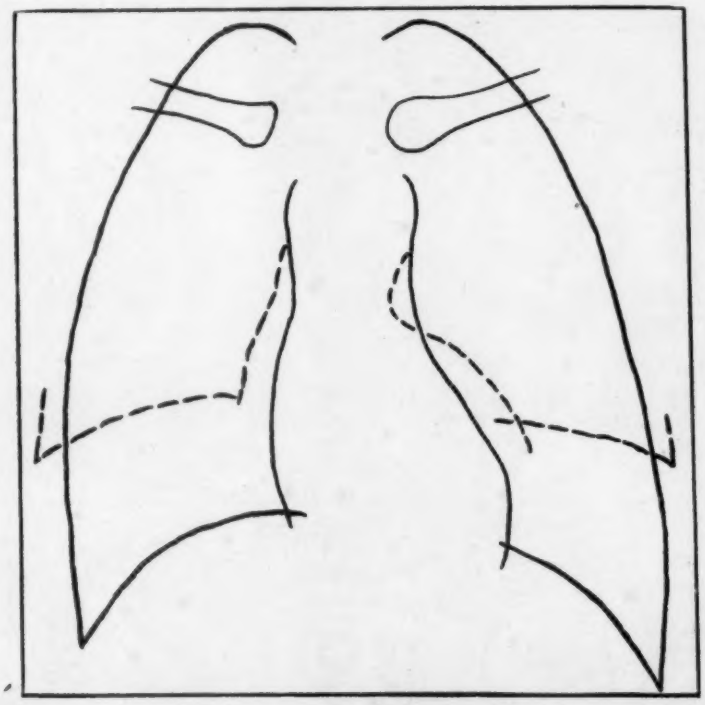


Fig. 3.—Diagram showing relative positions of the diaphragm before and after upper abdominal operations. The marked elevation after operation as indicated by the dotted line should be noted. Measurements were made from roentgenograms taken in the same position during full inspiration. The perpendicular from the transverse process of the first thoracic vertebra to a line through the dome of the diaphragm on each side was taken to indicate the degree of elevation.

		Before Operation	After Operation	Elevation
Average in 15 cases	Right perpendicular..	25.8 cm.	21 cm.	4.8 cm.
	Left perpendicular..	26.5 cm.	23 cm.	3.5 cm.

The alteration in thoracic volume from this factor alone should be noted.

The comparison of the roentgenograms made before and after operation was perhaps the most striking of all observations made in this study. In all of the cases, a definite diminution in volume of the chest

was obvious. There was a narrowing of the inter-rib spaces and an elevation of the domes of the diaphragm. The lung markings were clear in only six of the cases. In sixteen of the cases, there was a marked intensification of the trunk shadows which produced a triangular

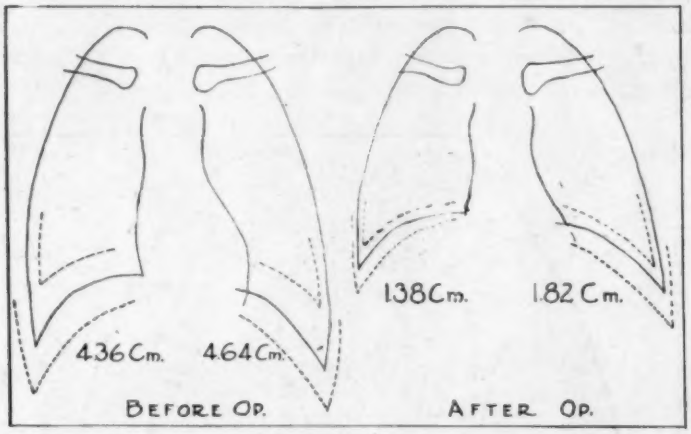


Fig. 4.—Diagram illustrating reduction in the maximal diaphragmatic excursions as averaged from studies in twenty-five cases before and after upper abdominal operations. The patients were studied in both the recumbent and the erect positions. It should be noted that after operation the movements are restricted by two-thirds.

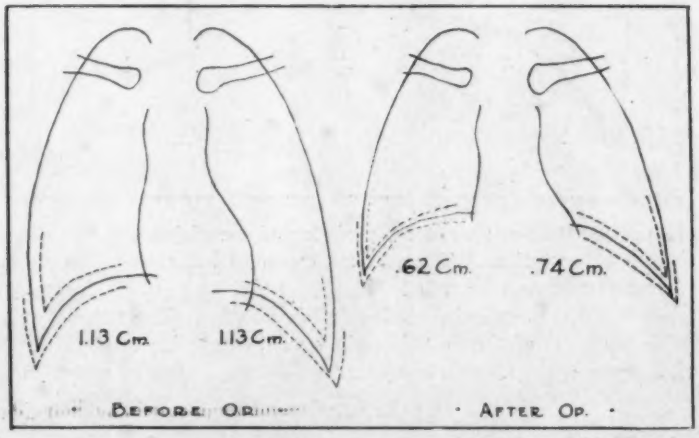


Fig. 5.—Diagram illustrating the limitation of the tidal movements of the diaphragm as averaged in fifteen cases before and after operation and with the patients in both the recumbent and erect positions. It should be noted that the postoperative movements were only one half of the normal.

area of density in the lower lobes. On the right, the cardiophrenic angle was obliterated. On the left, the markings were more or less obscured by the cardiac silhouette. In some of the roentgenograms, there were

varying degrees of haziness or mottling throughout the entire lung fields (figs. 6, 7, 9 and 10).

In the lateral views, the appearance was more striking. The marked reduction in the volume of the chest was clearly evident. The costophrenic angles posteriorly were completely obliterated. The marked diaphragmatic elevation obscured the lung detail in the lower lobes. Air was visible beneath the diaphragm in many of the films (fig. 8).

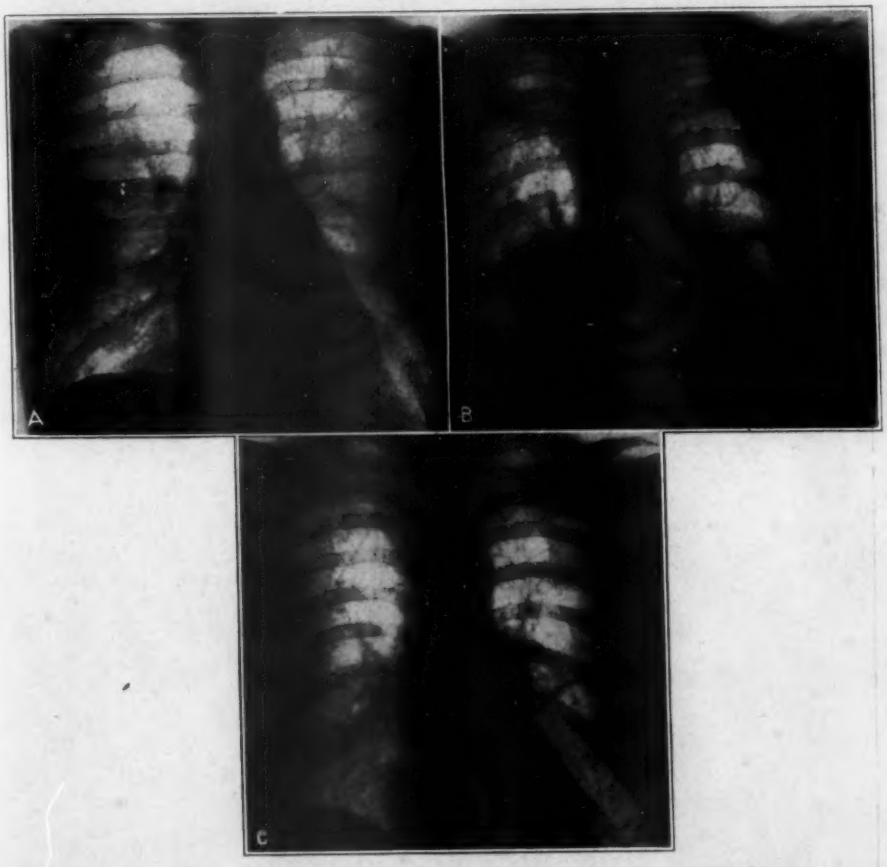


Fig. 6.—C. W., aged 49. *A*, roentgenogram at full inspiration made before operation for a large, adherent epigastric hernia. The roentgenographic studies in this case are presented because a second-stage pneumoconiosis intensifies the lung markings. *B*, roentgenogram at full inspiration made twenty-four hours after operation. The decrease in thoracic volume, elevated diaphragm, narrowed inter-rib spaces and prominent trunk shadows should be noted. The vital capacity was 25 per cent. *C*, roentgenogram at full inspiration made four days after operation. The partial return of the diaphragm to a normal position and increase in the thoracic volume should be noted. The vital capacity was 85 per cent of the normal.

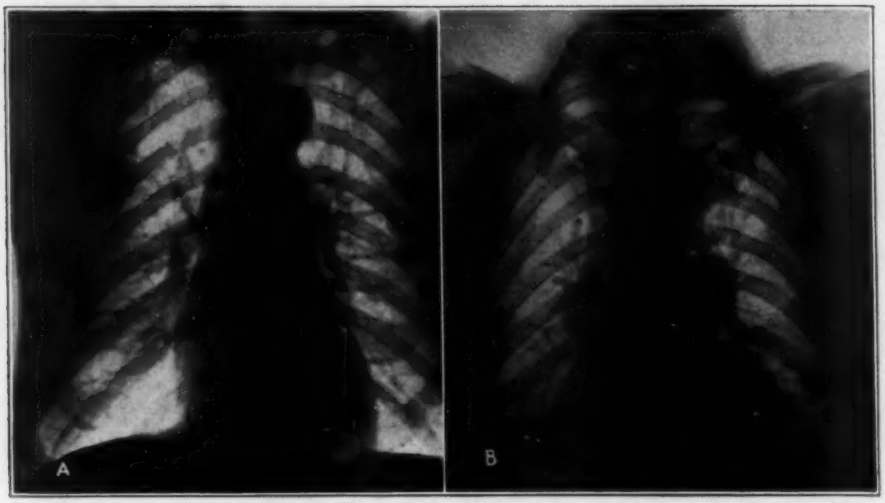


Fig. 7.—S. H., aged 53. *A*, normal roentgenogram made at full inspiration before cholecystostomy. *B*, roentgenogram made twenty-four hours after operation. The diminished thoracic volume, position of diaphragm and prominent trunk shadows should be noted. This patient had a normal postoperative course. The vital capacity was 32 per cent of the normal.

Fig. 8.—C. D., aged 32. *A*, lateral roentgenogram made before gastro-enterostomy. Bedside position. *B*, study made of same patient twenty-four hours after operation. The size of the aerated pulmonary tissue should be compared with the preoperative roentgenogram. The position of the diaphragm and obliteration of the costophrenic angle posteriorly should be noted. There is a large collection of air beneath the diaphragm. The vital capacity was 23 per cent of the normal.

Roentgenograms made preoperatively during full expiration gave similar appearances to those obtained at examinations made on the first postoperative day. They showed intensifications of the trunk shadows and alteration in the size of the aerated lung (figs. 9 and 10).

It will be noted in table 6 that in sixteen cases a diagnosis of hypoventilation was made. On the roentgenograms, all of these cases showed conditions that would have been diagnosed by us as postoperative pneu-

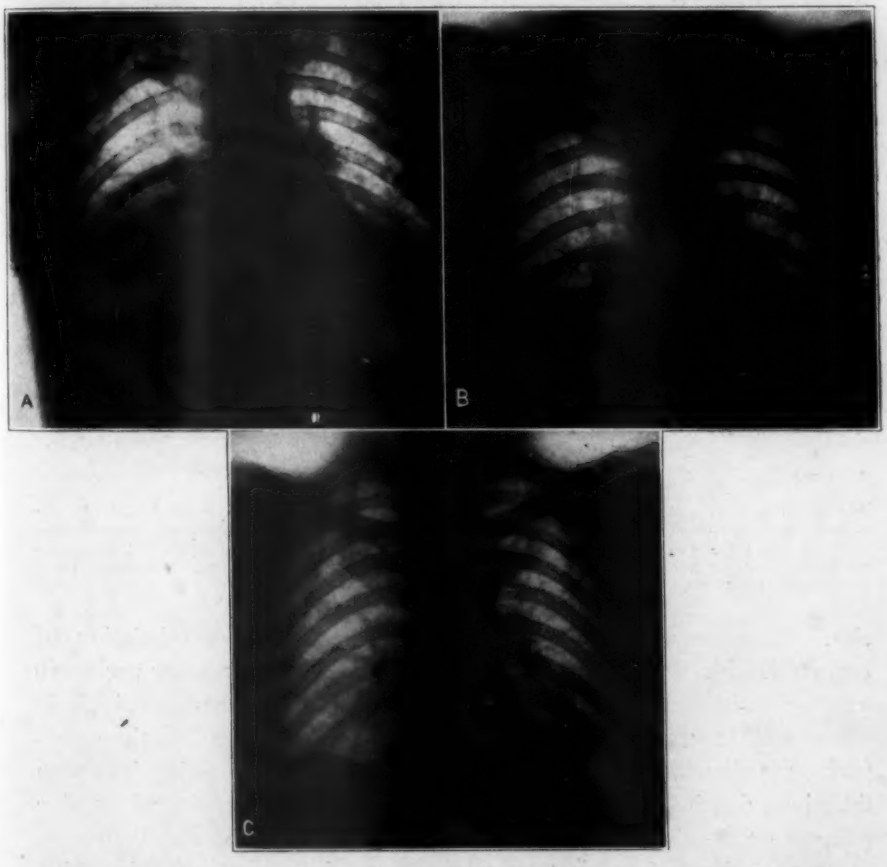


Fig. 9.—L. W., aged 39. *A*, roentgenogram made at full inspiration forty-eight hours after operation (perforated duodenal ulcer). The marked evidences of hypoventilation, the size of the thorax, position of the diaphragm and mottling of the lung fields should be noted. On physical examination of the chest, there was diminished resonance, suppressed breath sounds and later râles and tubular breathing at the bases. The vital capacity was 14 per cent of the reading taken three months later at follow-up study. *B*, roentgenogram made at full inspiration three months after operation. This plate was used as the normal for comparison. *C*, roentgenogram made after full expiration (follow-up study made three months postoperatively). The similarity between this induced hypoventilation and the study made at full inspiration twenty-four hours postoperatively should be noted.

monitis or lobular atelectasis prior to this study. Early in the study, we realized that these appearances (prominent trunk shadows and haziness of the lung fields) were normal postoperative manifestations.

In three of the patients of this series, a major pulmonary complication was demonstrated. In an elderly man, hemoptysis occurred two days after operation for gastric ulcer. The roentgenographic appearance was that of infarction at the right base. The temperature was normal for six days; then it became elevated. Physical signs and roentgenograms showed a diffuse lesion involving the left lower lobe. The patient was placed under an oxygen tent for five days and recovery followed. Both of the other two patients had operations on the gallbladder. In one, a man aged 60, there were cyanosis, dyspnea and physical signs of lack of aeration in the right lung. Roentgenograms

TABLE 6.—*Reviewed Cases* *

Patient	Operation	Excessive Temperature	Excessive Pulse	Postoperative Respirations	Pulmonary Symptoms	Pulmonary Signs	Positive Roentgenogram	Final Diagnosis
L. M.	Cholecystectomy...	+	+	—	+	+	+	Massive atelectasis
H. W.	Gastro-enterostomy	+	+	+	+	+	+	Infarct and bronchopneumonia
F. M.	Cholecystectomy...	—	+	—	—	+	+	Early stage massive atelectasis
Sixteen cases		—	—	3	2	16	16	Hypoventilation
Six cases		—	—	—	—	3	—	Negative

* In this table, the cases are grouped to show the relation of clinical signs and symptoms to roentgenologic observations and final diagnosis. The three cases which showed frank pulmonary complications are listed separately.

showed haziness of the entire right side. This cleared after inhalations of carbon dioxide, as suggested by Scott and Cutler.[25] The other patient in whom a pulmonary complication took place was a woman, aged 23, in whom a cholecystectomy had been done. Following operation, the roentgenogram showed cardiac and mediastinal displacement to the right with little lung density. On the following day, the typical density of massive collapse occurred in the middle and lower lobes. An elevation in temperature, pulse and respiratory rate was noted at this time only. The condition cleared in twenty-four hours, and convalescence was uneventful. This case is being reported separately, in detail.[26]

25. Scott, W. J. M., and Cutler, E. C.: Postoperative Massive Atelectasis; Effect of Hyperventilation with Carbon Dioxide, J. A. M. A. **90**:1759 (June 2) 1928.

26. Overholt, Richard H.; Pendergrass, Eugene P., and Leopold, Simon S.: Postoperative Massive Atelectasis; Report of an Unusual Case, Surg, Gynec. Obst., to be published.

COMMENT

The fact that there is hypoventilation of the lungs following upper abdominal operations has been referred to and commented on by many writers. However, in this study, the various physical measurements of the respiratory movements demonstrate more concretely the extent of this postoperative depression in pulmonary ventilation. The reduction

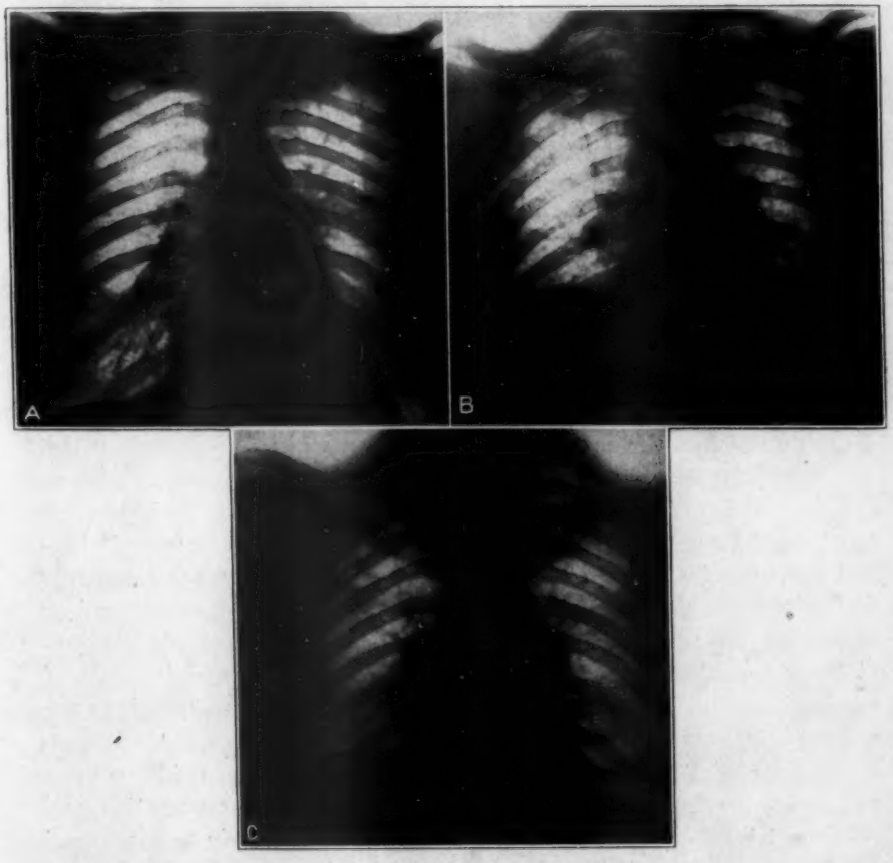


Fig. 10.—A. B., aged 50. *A*, roentgenogram made at full inspiration before cholecystectomy. *B*, examination made the day following operation during full inspiration. The vital capacity was 38 per cent of the normal. *B*, roentgenogram made before operation after full expiration. The similarity of appearances when compared with postoperative study after full inspiration should be noted.

of 79 per cent in expansion of the chest and the limitation of 66 per cent of the diaphragmatic excursions would indicate that a great portion of the reserve of the external respiratory forces was lost for a variable period of time following operation. The constant high position of the diaphragm with the tidal fluctuations occurring in the upper third of its

possible range of motion illustrates the mechanical disadvantage imposed on the diaphragm after upper abdominal operations.

The results of the determinations of vital capacity present further evidence that a state of pulmonary hypoventilation and a marked reduction in the reserve of respiratory function exist. The loss of three fourths of the lung capacity following operations on the upper part of the abdomen was shown both in this series and in reports by Churchill and McNeil,[21] Powers [22] and Head.[27] In our experience in cases presenting intrathoracic lesions which were known to be preventing the function of half of the pulmonary tissue, the reduction in vital capacity was no greater than that seen after upper abdominal operations. In this series, the two patients with a massive atelectasis of the entire right lung and the patient with bronchopneumonia and extensive involvement in both lower lobes did not have a reduction in vital capacity which exceeded that in the normal postoperative case.

The number of symptoms referable to the chest in these cases after operation seemed about what would be expected in such a series. From the paucity of pulmonary symptoms, the frequency of positive physical signs seemed abnormally high. However, after considering all of the forces acting to decrease the volume of the pulmonary system and the mechanical difficulties in aerating that portion which is left to function, it is surprising that every case after operation would not present positive physical signs. Even in nonoperative patients who are bedridden, it has been shown that areas at the bases occur over which abnormal physical signs can be elicited. In tuberculous patients, Sewall [28] frequently found positive chest signs such as diminished resonance, decreased or absent breath sounds and often râles. Even in normal persons, a physiologic atelectasis may result from a change in posture or in the vigor of respiration. In 1894, Abrams [29] referred to a state of atelectasis in the normal lung as well as in pathologic conditions.

Positive physical signs which might be regarded as evidence of a pulmonary complication have been elicited by us after operation and confirmed by the attending internist in a number of private cases, and yet further study and the subsequent course of events showed that the patients were suffering only from the effect of hypoventilation. The type of physical signs depends entirely on the degree of compression and the lack of aeration of the lower lobes.

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27. Head, J. R.: The Effect of Operation upon the Vital Capacity, Boston M. & S. J. **197**:83, 1927.

28. Sewall, Henry: Pulmonary Atelectasis as a Source of Confusion in Physical Examination of the Chest, Am. Rev. Tuberc. **4**:811 (Jan.) 1921.

29. Abrams, A.: Observations on Physiological Pulmonary Atelectasis, M. Rec. **46**:268, 1894.

With what has been said about the frequency of physical signs and the roentgenographic appearance in postoperative studies of the chest, it might seem that the diagnosis of pulmonary complications is difficult. In this series, three patients had frank pulmonary lesions (table 6) which were all distinguishable in the roentgenograms. The two cases of massive atelectasis showed the clinical picture as well. The case in which a diagnosis of bronchopneumonia was made showed the typical temperature chart of pneumonia. The temperature reaction seems the best indication of a frank complication. The respiratory rate and the pulse were not an indication of a complication. The evanescent character of the positive physical signs and the clearing of the lung markings on the roentgenogram as pulmonary ventilation improves would aid in ruling out a postoperative pulmonary complication.

The most interesting and important observation in this clinical study is that most postoperative roentgenograms present an appearance similar to that previously diagnosed as a true inflammatory pulmonary lesion, such as postoperative pneumonitis, bronchopneumonia, or what was considered a pathologic lobular atelectasis. There were only six cases in which the roentgenograms were clearly negative after operation. The other nineteen showed an increased prominence of the trunk shadows at both bases giving a triangular area of density which, on the right side, occupied the inner two thirds of the lung field, and on the left side was largely obscured by the superimposed cardiac shadow. In a few cases there was a mottling at the termination of the trunk shadows which we regarded as evidence of an atelectasis of the primary lobules with or without retained secretions.

In the lateral views, lung detail posteriorly was largely obscured because of the elevation of the domes of the diaphragm after operation.

The degree of the intensification of the trunk shadows and the haziness of the lung fields on the roentgenogram seems to be directly proportional to the degree of elevation of the diaphragm as shown by the perpendicular measurements of the chest. It was thought at first that the degree of intensity of the trunk shadows was determined in part by the type of case studied, i. e., in the short thick chested person the appearance was less striking. However, after reviewing all of the films, it was found that of the six cases in which the appearance was not present, there were four short thick chested patients and two who had long slender chests.

Additional evidence that the postoperative appearance of the roentgenograms is due to pulmonary compression and hypoventilation can be furnished from a comparison of bedside studies made before operation in the expiratory phase and the postoperative examinations made at full inspiration. In many cases, little difference in lung detail could be seen. In some, the diaphragmatic elevation and intensification of the

trunk shadows was more marked in the normal postoperative case than that found in the same case before operation during full expiration.

It has previously been observed that there are changes in the lung markings on the roentgenograms made during full expiration. Machlin [30] described shortening and narrowing of the bronchi, principally in the lower lobes. The changes are even more marked when bedside exposures are made. It is the experience of the roentgenologic department of the University Hospital that roentgenograms made in the expiratory phase in the erect posture do not show the marked intensification of the trunk shadows that were observed in this study after bedside examination.

That the evidences of hypoventilation in the postoperative case should be even more marked in some cases than that seen in the preoperative expiratory study can be explained by the fact that this hypoventilation is maintained over a period lasting several hours after operation. This prolonged hypoventilation and compression permit absorption of imprisoned air within partially collapsed alveoli, and true complete atelectasis then is present. The delayed appearance of tubular breathing elicited over these areas could be explained on the same hypothesis—that the maximum density of the atelectatic lung is not reached until the residual air is absorbed.

The observations made in this study lead us to believe that bronchial obstruction, per se, is not the primary factor in the production of atelectasis in the lower lobes after upper abdominal operation. It would seem that the active compression of the lower lobes due to the marked diaphragmatic elevation and the maintenance of this position over variable periods of time, together with the marked reduction in the pumping action of the diaphragm, are all factors which should receive the first consideration. No doubt the bronchi and bronchioles do become obstructed, but we think it results primarily because their lumen become smaller and the air current passing through them becomes stationary.

SUMMARY

1. A definite appearance (a prominence of the basal trunks, haziness of the lung fields and elevation of the dome of the diaphragm) found in the roentgenograms of patients after upper abdominal operations is due to hypoventilation of the lung, and this appearance should be regarded as normal.

2. This roentgenographic appearance is similar to that in cases in which the condition has been diagnosed previously as pulmonary complications, bronchopneumonia, postoperative pneumonitis, or as pathologic lobular atelectasis.

30. Machlin, Charles C.: X-Ray Studies on Bronchial Movements, Am. J. Anat. **35**:303, 1925.

3. The lung fields on the roentgenogram made at the height of the expiratory phase before operation are similar to those found in the roentgenograms made after operation during full inspiration. Both show evidences of decreased thoracic volume and diminished aeration.

4. Transient positive physical signs in the chest are found frequently after upper abdominal operations. A too hasty diagnosis of a pulmonary complication is not warranted from physical signs alone. Clinical signs and symptoms are of greater value and are usually present when a pulmonary complication exists.

5. Changes in chest expansion and in position and movement of the diaphragm as well as the change in pulmonary volume all explain the marked reduction found in the vital capacity of patients after upper abdominal operation.

6. The varying degrees of partial atelectasis which occur after upper abdominal operations are due primarily to diaphragmatic elevation and restriction.

ABSTRACT OF DISCUSSION

DR. GEORGE P. MULLER, Philadelphia: I have very little to say except that Dr. Overholt has worked hard on this study. We were assisted by Drs. Pancoast and Pendergrass of our roentgenologic department, who have shown great interest in this work on account of the results. This study really started as the result of an argument as to the pathologic condition of postoperative pulmonary complications, because routine roentgen examinations of the chest revealed more pulmonary complications than the clinical evidence seemed to warrant. After some preliminary work had been done, we became aware that there was some discrepancy between the so-called pneumonitis and the clinical aspects. That was the problem Dr. Overholt set to work to try to solve.

He has shown well that after operations on the upper part of the abdomen something occurs to the diaphragm which diminishes the air capacity of the lung, therefore giving an opacity at the base of the roentgenogram which will simulate the pathologic bronchopneumonia or atelectasis.

DR. KENNON DUNHAM, Cincinnati: I should like to inquire why the roentgenograms were always taken on expiration rather than on inspiration.

DR. WILLY MEYER, New York: This highly scientific and extensive follow-up before and after operation by Dr. Muller and his associates is most important.

Many of us have observed postoperative developments carefully from a clinical standpoint. Every older physician remembers, and the younger physicians have had the older ones tell them, that they always were most fearful of the postoperative complications of the lung.

Dr. Muller's study involves surgical work in the upper part of the abdomen, operations on the gallbladder, stomach and duodenum. All surgeons have seen lung complications follow just such operations in spite of a splendidly given general anesthesia as well as after a perfect regional and local analgesia.

From a mere empiric standpoint, my associates and I have been in the habit of advising the patients at the Lenox Hill Hospital in New York to start regular deep inspirations as soon as they have come completely out of the anesthesia. We tell the attending nurses to have these patients practice "gymnastics of the lungs" regularly and faithfully, and we tell the patients that the oftener they do it, the

better it is for them. They close their mouth, then slowly draw a deep inspiration through the nose until it begins to hurt at the seat of operation, and then try to do a little more. In other words, we start the pulmonary ventilation immediately after the operation and explain to the patient that "he has to get rid of the gas still circulating with his blood."

To my delight, I have just heard presented a scientific way of measuring regularly the circumference of the chest and, then, by means of interesting the roentgenographic department in the follow-up after operation, to study the immediate consequences of the operation in the working of the lungs from day to day. It shows "scientifically" the occurrence of the so-called massive collapse of the lung which Dr. Scrimger started discussing seven or eight years ago at the Congress of Clinical Surgeons at Montreal.

The study proves that it is almost a surgeon's duty to insist on this pulmonary ventilation in patients who have had general anesthesia, and the earlier it is done the better.

What causes the massive atelectasis still needs further investigation. I have had some interesting conversations here with a number of men regarding the so-called postoperative massive collapse, better called massive atelectasis. It seems to have been proved by members of the Washington University School of Medicine, by the younger students under the guidance of Dr. Graham, that contraction of the circular muscles of the bronchi evidently plays an important rôle. That seems to be the starting point of the so-called massive atelectasis. Later on, the viscid fluid that collects in the bronchioles and bronchi is added to the original effect of the mechanical contraction of the bronchi. But all this must first be definitely proved.

DR. E. A. GRAHAM, St. Louis: I also wish to add my word of congratulation to these interesting studies. I should also like to commend Dr. Meyer for his apparent success in getting his patients to take deep respirations after upper abdominal operations. I have tried to get patients to do that for a good many years and have not met with any great degree of success.

When Haggard and Henderson published their work about four or five years ago on the use of carbon dioxide for the purpose of washing ether out of the lungs, as they rather graphically expressed it, we began to use the inhalation of carbon dioxide on patients who had had ether anesthesia in a routine manner. Since that time, we have used it almost as a routine for patients who have had any anesthesia, particularly those on whom any kind of abdominal operation has been done. I was also much interested in Dr. Elliott Cutler's article in *The Journal of the American Medical Association* a year or two ago on the same subject, and I agree heartily with everything he had to say.

The difficulty about voluntary hyperventilation is that it is difficult to accomplish. A few whiffs of carbon dioxide, however, will compel the patient to take a deep respiration. We ordinarily start the use of carbon dioxide as soon as the anesthesia is stopped, that is, in the operating room before the wound is closed. Carbon dioxide tanks also are kept in the wards, and the nurses are instructed to give the patients inhalations of carbon dioxide at intervals of about every half hour if the patient is not breathing deeply. If the patient is breathing deeply, then some judgment is exercised by the nurse as to whether it is necessary to give a little carbon dioxide.

It is not necessary for the carbon dioxide to be kept up for any length of time. If the patient takes only two or three deep breaths, it seems to me that this is sufficient to accomplish a proper amount of pulmonary ventilation, enough to avoid massive atelectasis.

At any rate, about three years ago the medical service of the hospital asked, "Why is it you never call us in to see your cases of massive atelectasis? You must have them because everybody else has them."

My reply to that was that we sometimes had patients with high diaphragms, because at about the same period we made observations in about fifteen successive cases of cholecystectomy; when a roentgenogram was taken the next day we found a high diaphragm. These observations were never published.

Since that time, however, the medical service has been actively on our trail. I think that there has been only one case in about three years' time in which there has been anything like a frank, massive atelectasis of the lungs postoperatively. This occurred in a patient who, owing to a combination of circumstances, did not receive carbon dioxide inhalations after the operation.

I feel that this simple device will practically eliminate postoperative massive atelectasis, and that one will not have to depend on voluntary cooperation from the patient, because the patient cannot help taking deep respiration if he breathes a little carbon dioxide.

Dr. Pol N. Coryllos, New York: Dr. Overholt's work confirms the fact that after operations, especially on the upper part of the abdomen, the diaphragm is elevated and the vital capacity decreased. Furthermore, he showed that this decrease was due rather to the impairment of thoracic mobility than to reduction of the thoracic capacity. The elevation of the diaphragm, especially in operations on the abdomen, is due, I believe, to the contraction of the abdominal muscles, reflex as well as voluntary, which is the result of the pain following the operation. Besides, there is always a degree of intestinal paralysis and stagnation of gases in the bowel. Furthermore, contraction and immobilization of the abdominal wall cannot be accomplished without partial, at least, immobilization and splinting of the chest. A unilateral displacement of the diaphragm, however, cannot be explained in the same way. In these cases, in which as a rule, a more or less marked displacement of the heart to the side of the elevated diaphragm will be found if looked for, one should admit without hesitation the presence of atelectasis in the corresponding lung. Atelectasis is not always massive or lobular; most often it is partial. This explains the opacity noticed in the bases of the lungs in most of these cases. It should, however, be borne in mind that even simple compression of the pulmonary parenchyma suffices to give the impression of opacity because of the partial deflation from air of the corresponding portion of the lung. But elevation of the diaphragm alone cannot produce atelectasis as long as the bronchial tree is free. Apneumatosis cannot be produced by phrenicotomy alone. Clinical and experimental data have proved this point, which revived the theory of W. Pateux. I believe that it is time to associate closely atelectasis and bronchial obstruction, and to discard all other proved and provable theories of the pathogenesis of atelectasis, which only befog the question and interfere with its etiologic treatment. Elevation of the diaphragm is one of the several causes (posture, suppression of cough reflex, narcotics etc.) which lead to the accumulation of bronchial exudate in the bronchial tree, especially the most dependent parts of it. But, in these cases at least, there cannot be atelectasis unless there is an obstruction somewhere in the bronchial tree which makes possible the absorption of the intra-alveolar air. I do not deny the existence of lobular bilateral atelectasis of the bases; I will insist only on the fact that elevation of the diaphragm is the result and not the determining cause of atelectasis. Measures capable of increasing thoracic amplication and pulmonary ventilation will oppose the bronchial stasis and will help to prevent atelectasis. Hyperventilation with carbon dioxide acts in that way in preventing or even in curing atelectasis. Henderson, Scott and Cutler have insisted on that

point. In an experimental and clinical work on atelectasis as well as on lobar pneumonia, Dr. Henderson and I obtained interesting results, in which the hyperpnea produced by inhalation of carbon dioxide does not seem to be the only acting cause. It looks as if besides the mechanical action, there is a chemical action of the carbon dioxide inhaled, which may be of practical importance, especially if one bears in mind that, as a rule, the pneumococcus is present in the bronchial exudate in atelectasis.

DR. J. J. SINGER, St. Louis: I was interested in the description of the x-ray reports as given by the essayist. We have often found that the shadows on the roentgenograms are interpreted differently by different men. A shadow in the lung only means a lack of air content, but what causes it is another problem.

In a patient who is on the operating table for an hour or two, perfectly relaxed from an anesthesia and particularly from morphine, it is evident that the dependent parts of the lung would become less ventilated and more congested. Naturally, the lung would fill out less space, and the diaphragm would have to come up to fill out the space.

We have often been surprised to see definite signs of pneumonia in the lung a day or two after an operation, and then to find on the third day that all the physical signs have disappeared.

In 1914, when I first began to study roentgenograms of the chest, I noticed that many of the plates presented by the x-ray department were taken at various phases of inspiration. If one plate is taken today and another two or three days later, they would not look like plates of the same patient. I recall having a roentgenogram made of my own chest at inspiration and at expiration and showing them to my colleagues for their interpretation. A diagnosis of tuberculosis was made from the one taken at expiration. It was purely a matter of lessened expansion, and I think that if every one watches his roentgenograms a little more carefully and interprets them properly, there will be fewer diagnoses of postoperative complications.

DR. RICHARD H. OVERHOLT: Dr. Dunham asked why the plates were taken after expiration. In only about half the cases were plates made after expiration. In all cases, plates were taken at full inspiration. The expiratory films were taken before operation in order to compare them with the postoperative inspiratory plates; both showed hypo-aeration of the lung.

Dr. Graham mentioned the use of carbon dioxide after operation. To all of these patients who received general anesthesia, carbon dioxide was given at the end of the operation. In only one case was carbon dioxide used as well after the patient had been returned to the ward. This was a patient who we thought was developing a massive atelectasis.

Five of these patients were operated on under spinal anesthesia. Most of them were given ether or gas-oxygen combined with procaine hydrochloride locally. The appearance was just the same in cases in which the operation was done under spinal anesthesia; so nothing was said about the type of anesthetic. We feel that the type of anesthetic has no effect on the subsequent appearance of the postoperative roentgenograms.

I was glad that Dr. Singer mentioned the interpretation of the roentgenograms. Early in the study we thought that we were getting complications in all patients, but we later realized it was merely a mechanical change, or cloudiness, as a result of poorly ventilated lung tissue. We feel that this is one of the most important points in this study. We wanted to emphasize the necessity of careful interpretation of the postoperative films. It would be well to check the roentgenograms

made early after operations with those made two or three days later to see whether the same appearance is there.

Dr. Coryllos has called attention to the importance of this whole subject in its relation to the position of the diaphragm. We are now going ahead with this study in an attempt to explain just why the diaphragm does ascend so universally. Atelectasis, to a certain degree, occurs in all these cases in the lower lobes after operation and must be dependent primarily on the position of the diaphragm.

From studies on vital capacity taken from records made after operation, we feel that the pain in the abdomen on the first day will not explain this marked reduction in ventilation, or the 75 per cent reduction in vital capacity. Certainly there is some other factor besides the pain from the abdominal wound that cuts down respiratory activity.

In giving patients morphine after operation and testing their vital capacity at various intervals following such administration, we found that the vital capacity is changed little in those in whom upper abdominal operations were performed. The vital capacity in the patients with lower abdominal operations was greatly improved. In cases of hernia or following appendectomy, the abolition of pain will greatly improve the vital capacity, but will not improve it to such a marked degree following the upper abdominal procedures.

THE CIRCULATION IN THE COMPRESSED, ATELECTATIC AND PNEUMONIC LUNG

(PNEUMOTHORAX-APNEUMATOSIS-PNEUMONIA) *

POL N. CORYLLOS, M.D.
Professor of Clinical Surgery, Cornell University Medical College
AND
GEORGE L. BIRNBAUM, M.D.
Assistant in Surgical Research, Cornell University Medical College
NEW YORK

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INTRODUCTION

Despite an extensive literature on the circulation in the compressed, collapsed or consolidated lung in pneumothorax, massive atelectasis and lobar pneumonia, we have as yet only few definite ideas on this subject. Views which are most varied, if indeed not diametrically opposed, are

* From the Department of Surgical Research, Cornell University Medical College.

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upheld by different investigators. For the atelectatic lung, opposite theories have been brought forth: (1) an increased blood flow with an impoverishment of blood supply to the healthy lung (Cloetta,[1] Sauerbruch[2]); (2) a more or less complete suppression of circulation in the affected lung (Weber,[3] Brauer,[4] Bruns,[5] Propping,[6] Yates,[7] Torek,[8] etc.).

For lobar pneumonia, the same divergence of opinion exists. Lundsgaard and van Slyke,[9] reviewing different theories relating to the mechanism of the production of cyanosis, said: "We are yet uncertain concerning the main factor in preventing reoxygenation of the blood in the lungs; . . . insufficient oxygenation of blood passing aerated lung tissue or a fraction of blood passing consolidated lung tissue." Stadie[10] found "extensive consolidation without cyanosis, which is against the idea of a shunt . . . that is to say an intact circulation in the unaerated consolidated lung." Ribbert,[11] Kline and Winternitz,[12]

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1. Cloetta, M.: Ueber die Zirkulation in der Lungen und Beeinflussung durch ueber und unter Druck, Arch. f. exper. Path. u. Pharmakol. **66**:409, 1911. Cloetta, M., and Anderes, E.: Besitzen die Lungen Vasomotoren, ibid. **76**:125, 1914. Anderes, E., and Cloetta, M.: Eine weitere Methode zur Prüfung der Lungenzirkulation, Arch. f. exper. Path. u. Pharmakol. **79**:291, 1915; Die Beweis für die Kontraktilität der Lungengefässen, ibid. **79**:301, 1916.

2. Sauerbruch, F.: Zur Pathologie der öffenen Pneumothorax, Mitt. a. d. Grenzgeb. d. Med. u. Chir., 1904, vol. 13.

3. Weber, E.: Ueber active Aenderungen der arteriellen Blutfülle der Lungen, Arch. f. Anat. u. Physiol., Suppl., 1914, p. 377; 1912, p. 383.

4. Brauer, L., quoted by Lundsgaard, C., and van Slyke, D.: Cyanosis, Baltimore, Williams & Wilkins Company, 1923, p. 22.

5. Bruns, O.: Ueber die Blutzirkulation in der atelectatischen Lunge, Deutsches Arch. f. klin. Med. **108**:469, 1912.

6. Propping, K.: Ueber den Blutgehalt der Pneumothoraxlunge, Arch. f. klin. Chir. **112**:445, 1919.

7. Yates, J. L.: The Significance of the Vital Capacity in Intrathoracic Surgery, Arch. Surg. **12**:257 (Jan.) 1926; Effects of Acute and Chronic Pneumothorax, Am. J. M. Sc. **1**:165, 1923.

8. Torek, F.: In Discussion of papers on "Acute and Chronic Nontuberculosis Bronchopulmonary Suppurative Lesions, Arch. Surg. **16**:316 (Jan.) 1927.

9. Lundsgaard, C., and van Slyke, D.: Cyanosis, Baltimore, Williams & Wilkins Company, 1923, p. 43.

10. Stadie, W. C.: The Oxygen in the Arterial and Venous Blood in Pneumonia and Its Relation to Cyanosis, J. Exper. Med. **30**:215, 1919; The Treatment of Anoxemia in Pneumonia in an Oxygen Chamber, ibid. **35**:337, 1922.

11. Ribbert: Ueber die Ursachen der Blutarmuth grau hepatizierter Lungen, Virchows Arch. f. path. Anat. **136**:363, 1894.

12. Kline, B. S., and Winternitz, M. C.: Studies upon Experimental Pneumonia in Rabbits: 8. Intravitam Staining in Experimental Pneumonia and the Circulation in the Pneumonic Lung, J. Exper. Med. **21**:304, 1915.

Gross,[13] Binger and others,[14] on the other hand, tried to show that in pneumonia the circulation is completely cut off in the consolidated lobe. Peabody [15] and Butterfield and Peabody [16] contended that in most cases of uncomplicated pneumonia the decrease in respiratory surface is completely compensated and the oxygen content of the blood is within normal limits; Peabody [17] and Harrop [18] suggested that in rabbits that had received injections of pneumococcus as well as in cases of influenza and influenzal pneumonia in man, the respiratory distress and cyanosis are due to partial conversion of hemoglobin to methemoglobin. But the presence of methemoglobin has never been proved spectroscopically. Lundsgaard and van Slyke [9] concluded that "the question is of theoretical and practical importance in many respects and needs further investigation."

During our experimental work on massive atelectasis and lobar pneumonia, we were repeatedly faced with this question and decided to investigate it thoroughly. We concentrated chiefly on the circulation in the small branches of the pulmonary artery, and more especially in the capillaries. Injections of different substances were given into the pulmonary circulation in the living animal. The roentgenographic pictures obtained with injection of iodized oil, which showed the condition of the circulation in the branches of the pulmonary arteries and the histologic preparations after intravenous injections of india ink showing the changes occurring in the capillary circulation, demonstrated clearly that none of the foregoing theories is entirely correct. We came to the conclusion that in the three aforementioned pulmonary conditions there is an impairment of the capillary—and only the capillary—circulation; but this is due exclusively to the collapse of the alveoli. The impairment of the circulation follows and is caused by the impairment of the alveolar ventilation. There is no obstruction in the branches of the pulmonary artery and the impairment of the capillary circulation is due neither to the obstruction by emboli nor to compression by intra-alveolar exudate.

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13. Gross, L.: The Blood Supply to the Pneumonic Lung, Canad. M. A. J. **9**:632, 1919.

14. Binger, C. A. L., and Brow, G. R.: Studies on the Respiratory Mechanism in Lobar Pneumonia, J. Exper. Med. **39**:677, 1924. Binger, C. A. L.; Christie, R. V., and Ehrich, W.: Diathermy in Pneumonia, J. A. M. A. **91**:367 (Aug. 11) 1928.

15. Peabody, F. W.: The Oxygen Contents of the Blood in Rabbits Infected with Pneumococcus, J. Exper. Med. **18**:1 (July) 1913; The Oxygen Content of the Blood in Lobar Pneumonia, ibid., p. 7.

16. Butterfield and Peabody, quoted by Austrian, C. R.: Pneumonia in Tice: System of Medicine, Hagerstown, Md., W. F. Prior, 1920, vol. 3, p. 1.

17. Peabody (footnote 15, first reference).

18. Harrop, G. A.: The Behavior of the Blood Toward Oxygen in Influenzal Infections, Bull. Johns Hopkins Hosp. **30**:10, 1919.

We shall first give a short résumé of a few points in the physiology of the circulation in the lung in relation to respiration, which will be followed by a review and discussion of theories on the circulation in the atelectatic and pneumonic lung. Our experimental observations and our conception of the question, based on them, will then follow.

THE CHEMISTRY OF RESPIRATION

As long as alveolar ventilation and circulation in the pulmonary capillaries are normal, the gas exchange will be normal, and the volumes of oxygen and carbon dioxide will show a remarkable constancy; but if ventilation is impaired by (1) changes in the inspired air, (2) an increase in the thickness of the septums which separate the air sacs from the circulating blood or (3) obstruction of the bronchi or bronchioli, then more or less marked alterations in the partial pressures of oxygen and carbon dioxide in the venous, and particularly the arterial, blood will occur, accompanied by modifications in the p_H of the blood and changes in the urine.

In the case of bronchial obstruction, if the circulation remains intact, an amount of blood will circulate through unaerated channels; it will be overcharged with carbon dioxide, pass through the pulmonary veins into the left side of the heart and pollute the arterial blood. In this way the criterion of persistent circulation in unaerated portions of the lung will be the increase of the partial pressure of carbon dioxide in the arterial blood.

Normally, the partial tension of oxygen in the alveolar air is 107 mm. of mercury, and of carbon dioxide 40 mm. The tensions of the gases in the venous blood in the lung capillaries (Loewy[19]) are: oxygen = 5.3 per cent = 37 mm. of mercury; carbon dioxide = 6 per cent = 46 mm. of mercury. There is thus a difference of tension of oxygen between the alveolar air and the blood of 107 — 37 = 70 mg. of mercury, which will tend to cause a passage of oxygen from the alveolar air to the circulating blood. The total surface of the lung should be, according to Hufner,[20] about 140 square meters; even if it has a minimal measurement of 90 square meters, this would be equal to 1,000 square feet. On the other hand, the thickness of the septums separating the capillaries from the alveoli, in which the blood circulates, is a layer no more than one red corpuscle thick, or about 0.004 mm. According to the figures given by Loewy and Zuntz relative to the speed of diffusion of gases, under an alveolar oxygen pressure of only 35 mm. of mercury, 6.7 cc. of oxygen can

19. Loewy, in Starling: Principles of Human Physiology, Philadelphia, Lea & Febiger, 1915, p. 907.

20. Hufner, in Starling: Principles of Human Physiology, p. 907.

pass through a square centimeter of the alveolar wall in a minute. This amounts to 6,083 cc. of oxygen per minute through the whole surface of the lung, or over 360,000 cc. per hour. The oxygen actually absorbed by a man averages only 350 cc. per kilogram of body weight per hour, or about 20,000 cc. per hour for a person weighing 60 Kg.; this gives an ample margin of safety for increased oxygen consumption; in fact, a difference of pressure of a couple of millimeters would suffice to cause a passage of 300 cc. per kilogram per hour, which is required by the resting man. In the same way it is easy to account for the passage of carbon dioxide in the reverse direction, especially since this gas diffuses twenty-five times as rapidly as oxygen, so that a difference of pressure between the blood and the alveolar air amounting to only 0.3 mm. of mercury would suffice to cause a passage into the alveoli of the 300 cc. of carbon dioxide per kilogram normally expired per hour. We wish to emphasize these figures, which show that in the resting man (or animal) only one-twentieth part of the total surface of the lung is sufficient to insure a normal oxygenation of the blood. A great part of the lung, therefore, could remain unaerated before respiratory disturbance would ensue. This margin of safety, however, is greatly lessened if for any reason the thickness of the septums separating the blood from the alveolar air is increased, as in edema of the alveolar wall, bronchitis (Hoover [21]) or poisoning from gas (Barcroft, Hunt and Dufton [22]). Brauer [4] created the term "pneumonosis" to indicate decreased permeability of alveolar epithelium.

Another important point in the chemistry of respiration is the relation of carbon dioxide tension to the dissociation curve of oxyhemoglobin. With a normal tension of oxygen in the alveolar air (107 mm. of mercury) and of carbon dioxide (40 mm. of mercury), the hemoglobin is 95 per cent saturated. But if the pressure of oxygen falls to 40 mm. of mercury, with a carbon dioxide pressure of 40 mm., the hemoglobin is only about 65 per cent saturated; and at 30 mm. alveolar oxygen pressure it is only 50 per cent saturated (Bohr, Hasselbach and Krogh [23]). It has been shown that carbon dioxide acts to split oxygen from oxyhemoglobin, so that as the blood picks up carbon dioxide in its passage through the capillaries, oxygen is liberated from the oxyhemoglobin more readily than would otherwise be possible.

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21. Hoover, C. F.: On the Relation Between Blood Flow and Alveolar Ventilation, J. A. M. A. **71**:880 (Sept. 14) 1918.

22. Barcroft, J.; Hunt, G. H., and Dufton, D.: The Treatment of Chronic Cases of Gas Poisoning, Great Britain Medical Research Committee, Reports of the Chemical Warfare Medical Committee **4**:13 (April) 1918.

23. Bohr, C.: Hasselbach, K., and Krogh, A.: Ueber einen in biologischer beziehung wichtigen Einfluss, den die Kohlensaurespannung auf dessen saverstoffbindung übt, Skandin. Arch. f. Physiol. **16**:402, 1904.

Moreover, the pressure of salts in the red blood corpuscles greatly influences the dissociation curve of oxyhemoglobin which, in the absence of these salts, takes on the form of a rectangular hyperbola (Barcroft and Roberts [24]).

In the venous blood, as we have seen, the partial pressure of oxygen is 37 mm. of mercury and of carbon dioxide is 46 mm. The carbon dioxide is combined with the alkalis of the blood. There is a close relation between oxygen and carbon dioxide. Increase of carbon dioxide shifts the dissociation curve of oxyhemoglobin to the right, and a like increase in oxygen helps to liberate carbon dioxide from the blood. As Bohr and Halberstadt,[25] Haldane [26] and others have shown, more carbon dioxide is given off into the air when oxygen is present. If one lung is ventilated with air and the other with hydrogen, the lung ventilated with air gives off nearly 50 per cent more carbon dioxide than the lung ventilated with hydrogen. Conversely, the blood takes up considerably more carbon dioxide in the absence of oxygen. Oxygenation reduces the carbon dioxide capacity of the blood to such an extent that the partial pressure of carbon dioxide is raised and it can be given off by the blood in the lungs when the carbon dioxide pressure is considerably lower than that of the alveolar air. Thus excessive breathing "washes out" the carbon dioxide of the blood; if such breathing is kept up for a sufficient time it can produce coma and progressive failure in the circulation due to an excessive rise of p_H (alkalosis), as Henderson [27] showed. In these cases the available alkali in the blood increases, contrary to acidosis due to excess of carbon dioxide where the available alkali decreases. Henderson and Haggard [28] noticed that dangerous symptoms were produced in animals by any considerable increase of the available alkali in the blood when the increase was produced by excessive artificial respiration. Anoxemia, on the contrary, is the condition in which the partial pressure of oxygen in the systemic capillaries is abnormally low. It is due to defective saturation of the arterial hemoglobin with oxygen. Haldane, Meakins and Priestley,[29] in experimenting with their "concertina apparatus" by which

24. Barcroft, J., and Roberts, F.: The Dissociation Curve of Hemoglobin, J. Physiol. **39**:143, 1909-1910.

25. Bohr and Halberstadt, in Nagel: Handbuch der Physiologie des Menschen, 1905, vol. 1, p. 208.

26. Haldane, J. S.: Respiration, New Haven, Yale University Press, 1922.

27. Henderson, Yandell: Acapnia and Shock, Am. J. Physiol. **21**:126, 1908; **23**:345, 1908-1909; **24**:66, 1909; **25**:310 and 385, 1909-1910.

28. Henderson, Y., and Haggard, H. W.: Haemato-Respiratory Function, J. Biol. Chem. **39**:163, 1919.

29. Haldane, J. S.; Meakins, J. C., and Priestley, J. G.: The Effects of Shallow Breathing, J. Physiol. **43**:3, 1920; **42**:433, 1919.

"shallow breathing" was realized in normal persons, found that when the depth of the respirations was gradually more and more limited the breathing became periodic. Periodic breathing is a characteristic symptom of anoxemia, and it is promptly abolished when a little oxygen is added to the inspired air. According to these authors, the anoxemia is due to unequal and insufficient expansion of the lungs and to the relative increase of the dead space and the uneven ventilation of the alveoli. As a consequence, the venous blood passing through unexpanded parts of the lungs will be imperfectly oxygenated. The amount of oxygen will decrease, although in the expanded portion of the lung hyperventilation prevails and the effect will be a "washing out" of carbon dioxide with an insignificant increase of the oxygen. This is so because the oxygen pressure is only from 16 to 18 per cent of an atmosphere and little oxygen can be taken up by the blood, as is shown by the respective dissociation curves for oxygen and carbon dioxide present in the blood (Haldane [30]). Another cause of anoxemia is inflammation of the alveoli, which prevents a sufficient volume of oxygen from passing into the blood. This was observed in cases of chlorine poisoning during the war, and is the cause of cyanosis in bronchitis or edema of the lung, etc. The passage of the blood through unaerated channels is another cause of anoxemia, and such a condition obtains in the first stages of atelectasis or pneumonia.

Study of the chemistry of respiration leads to the conclusion that there is an intimate connection between respiration and circulation. Henderson,[27] in a series of papers on "Acapnia and Shock," showed that the local circulation in tissues is regulated in accordance with the local carbon dioxide pressure. Haldane,[31] in his remarkable book on respiration, said: "The main fact must never be lost sight of that the primary factor in determining the rate of circulation is neither the heart nor the venous centers but the metabolic activities of the tissues. At bottom, the regulation of the circulation is a chemical regulation, just as in the case of deep breathing"; this chemical regulation is as accurate and delicate as the regulation of breathing. These conclusions added to the important discovery of Krogh [32] of the opening or closing of capillary paths according to local tissue necessities will help us to a better understanding of our subject; for this reason, we feel justified in having dealt at some length with the chemistry of respiration.

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30. Haldane (footnote 26, p. 136, fig. 45).

31. Haldane (footnote 26, p. 279).

32. Krogh, A.: The Supply of Oxygen to the Tissues and the Regulation of the Capillary Circulation, Am. J. Physiol. **42**:457, 1919; Anatomy and Physiology of Capillaries, New Haven, Yale University Press, 1922.

THE CAPILLARY SYSTEMS OF THE LUNG

Precise knowledge of the capillary systems of the lung, pulmonary and bronchial, their interrelations and relative importance and functions, is necessary for a clear understanding of their pathologic processes.

Bronchial System of Vessels.—Miller,[33] in a series of papers, showed that the bronchial artery distributed itself along the entire length of the bronchi, giving small branches which form capillary plexi in the submucosa of the bronchi and bronchioli (as far as the respiratory bronchioli and ducti alveolaris) around the bronchial glands and even in the septums between the alveoli (fig. 1). At almost regular intervals these capillaries join venous radicals which are situated in the mucosa. These venous radicals form a rectangular plexus corresponding to the long axis of the bronchus. From this venous plexus, branches pass through the muscular layer and form a second plexus which is situated along the boundary line between fibrosa and muscularis. The second plexus is the source of venous radicals which, in the deeper part of the lung, form one of the sources of the pulmonary vein; these correspond to the bronchopulmonary veins of Le Fort. On the other hand, the venous radicals which arise from the first two or three divisions of the bronchi do not join the pulmonary vein, but form the true bronchial veins which empty into the azygi, the intercostal veins or the superior vena cava. The important point is that although there are no anastomoses between bronchial arteries and pulmonary arteries, the bronchial capillaries, partly at least, communicate with the pulmonary vein system through the bronchopulmonary veins of Le Fort.

When berlin blue in gelatin under pressure of 112 mm. of mercury is injected into the pulmonary artery, the pulmonary vein being open, the bronchial vessels will not be injected (Miller[34]). If the injection is made into the pulmonary vein, the pulmonary artery being open, the bronchial vessels will be partially injected. The same will occur if the injection is made into the pulmonary artery, the pulmonary vein being clamped, the berlin blue thus passing retrograde from the capillaries of the pulmonary vein to the bronchial capillary system. But if the injection is made into the pulmonary vein, the pulmonary artery being clamped, there will be a complete injection of the bronchial vessels. This is a clear demonstration of the absence of anastomoses between bronchial arteries and pulmonary arteries; that direct communication between bronchial vessels and the pulmonary venous system exists, is established

33. Miller, W. S.: The Arrangement of the Bronchial Blood Vessels, Anat. Anz. **28**:432, 1906; The Lobule of the Lung and Its Blood Vessels, J. Morphol. **24**:459, 1913; Anat. Anz., 1892, vol. 7; Das Lungenlappchen, seine Blut-und Lymphgefässe, Arch. f. Anat. u. Physiol., Anat. Abt., 1920, p. 197.

34. Miller (footnote 33, first reference).

by the following experiment: Miller injected berlin blue in 8 per cent gelatin into the pulmonary vein until it flowed freely from the pulmonary artery. The pulmonary vein was clamped and gelatin containing 8 per cent vermilion granules in suspension was forced into the

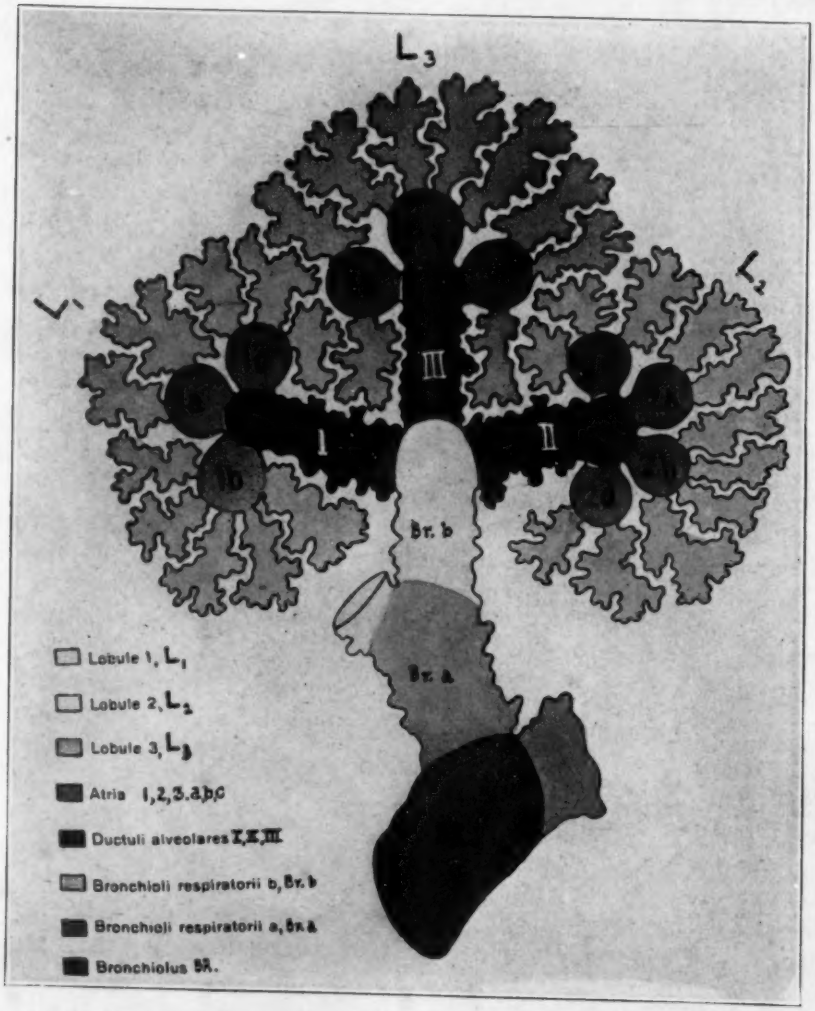

Fig. 1.—Scheme of the air-ways in three lobules of the lungs (after William Snow Miller).

pulmonary artery. The artery showed red, whereas the pulmonary vein and bronchial vessels showed blue. This explains the congestion of the bronchial vessels by a stasis in the pulmonary venous system.

Pulmonary System of Vessels.—The pulmonary capillary system is less complicated than the bronchial. The pulmonary arteries follow the

bronchi and rapidly divide, so that for each bronchus and bronchiolus there is an artery which follows it closely and gives branches to the ducti alveolaris before they are reduced to capillaries around the sacculi. The capillary systems of adjacent alveoli communicate intimately (Sauerbruch [35]) and are not independent as is so often stated in textbooks. In figure 2 this disposition is clearly shown. These capillaries join venous radicals which unite to form the interlobular veins that extend from the periphery of the alveoli toward the hilum to join a corresponding lobar vein at the proximal region of the bronchioli. Before reaching this point, they receive a part of the blood of the bronchial plexi at the height of the ducti alveolaris and respiratory bronchioli.

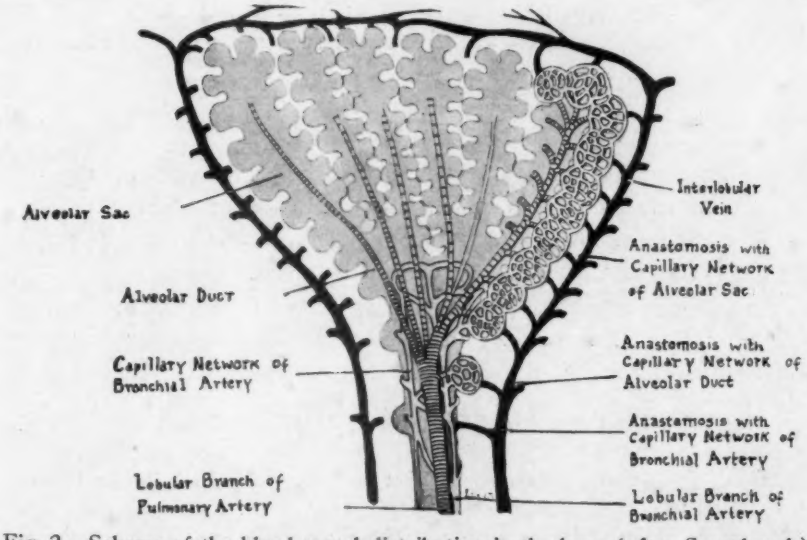
Alveolar Sac
Alveolar Duct
Capillary Network of Bronchial Artery
Lobular Branch of Pulmonary Artery
Interlobular Vein
Anastomosis with Capillary Network of Alveolar Sac
Anastomosis with Capillary Network of Alveolar Duct
Anastomosis with Capillary Network of Bronchial Artery
Lobular Branch of Bronchial Artery

Fig. 2.—Scheme of the blood vessel distribution in the lung (after Sauerbruch).

It is therefore not possible to concede a separation of the two capillary systems, the respiratory (pulmonary artery and vein) and the trophic (bronchial artery and vein). The pulmonary capillaries cover all of the respiratory field of the lung, that is, the alveolar sacs, the atria, the alveolar ducts and the respiratory bronchioli. The bronchial capillary system extends over the bronchi, bronchioli, interalveolar septums and even the respiratory field in order to insure their nutrition. But the bronchial capillaries do not go farther than the ducti alveolaris and the interalveolar septums, so that the nutrition of the alveoli beyond is insured by the pulmonary capillary system. On the other hand, in the walls of the respiratory bronchioli and the ducti alveolaris, there are

35. Sauerbruch, F.: Die Chirurgie der Brustorgane, Berlin, Julius Springer, 1920, vol. 1, p. 79

numerous air sacs, so that in these regions the bronchial capillaries function as part of the respiratory system. Hyrtl [36] showed that injections through small bronchial arteries always reach the venous alveolar capillaries. Therefore, no sharp distinction between respiratory and nutritive systems can be made in the lung, the pulmonary veins carrying back a part of the blood of the bronchial capillaries. This fact explains why ligation of a branch of the pulmonary artery in animals and in man does not interfere with the nutrition of the alveoli, as Sauerbruch has shown.

Cohnheim and Litten [37] did not believe that there was any communication between the two capillary systems. It was Küttner [38] who first suggested the wide anastomosis between the two systems, from observation in the frog's lung. Haller,[39] Hyrtl,[40] Henle,[41] Luschka [42] and Virchow [43] maintained that extensive anastomoses exist, and to this view Cohnheim and Litten [37] were later converted.

PATHOLOGIC PHYSIOLOGY

The anastomotic disposition of the vascular systems of the lung will regulate the alterations which follow isolated or concomitant ligations or obstructions of one or more of the vessels of the lung—pulmonary artery, pulmonary vein or bronchial vessels.

Ligation of a branch of the pulmonary artery (Bruns,[5] Sauerbruch,[35] Schlaepfer [44] and Smirnoff [45]) is followed by shrinkage and atelectasis with fibrous sclerosis of the corresponding portion of the lung. These

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36. Hyrtl, J.: Die Corrosions-Anatomie und ihre Ergebnisse, Vienna, Wilhelm Braumüller, 1873, p. 93.

37. Cohnheim, J., and Litten, M.: Ueber die Folgen der Embolie der Lungenarterien, Virchows Arch. f. path. Anat. **65**:99, 1875.

38. Küttner, H.: Beitrag zu den Kreislaufsverhältnisse der Froschlunge, Virchows Arch. f. path. Anat. **61**:21, 1874; Beitrag zur Kenntniss Kreislaufsverhältnisse der Saugethierelunge, ibid. **73**:476, 1878.

39. Haller, A.: Icones Anatomicae. Tabulas Arteriarum Bronchialium, Göttingen, B. A. Vandenhoeckii, 1756, pt. 8, p. 31.

40. Hyrtl, J.: Lehrbuch der Anatomie, ed. 2, Vienna, W. Braumuller, 1851; footnote 36.

41. Henle, F. G. J.: Handbuch der Eigenweidslehre des Menschen, Braunschweig, F. Viewig u. Sohn, 1866.

42. Luschka, H.: Die Anatomie des Menschen, Tübingen, H. Laupp, 1863, vol. 2, p. 316.

43. Virchow, R.: Gesammte Abhandlungen zur wissenschaft lichen Medizin, Frankfurt, Meidinger u. Sohn, 1856, p. 295.

44. Schlaepfer, K.: The Effect of Ligation of the Pulmonary Artery on One Lung Without and With Resection of the Phrenic Nerve, Arch. Surg. **13**:623 (Nov.) 1926.

45. Smirnoff, S. A.: Ueber die Folgen der Unterbindung der Lungenarterien, Arch. f. klin. Chir. **141**:512, 1926.

alterations are more marked the longer the period of ligation. In nine dogs, Smirnoff [45] ligated the pulmonary branch of the lower left lobe. He killed the animals in from ten days to one year and four months. In all cases he noticed "shrinkage of lobe; the lung parenchyma has taken on a solid and airless consistency. Small pieces sink in water. There is a complete physiologic suppression of the lung." None of the aforementioned authors or Küttner,[46] Kawamura,[47] Ritter and Ostrowsky [48] has ever had a hemorrhagic infarction of the corresponding part of the lung.

Four months after ligation of the pulmonary branch to the left lower lobe, this part of the lung was transformed into "a short solid band."

Sixteen months after ligation, the lobe was extremely small and fleshy, sank in water and had undergone a "fibrous atrophy." Smirnoff [45] does not favor the term used by Sauerbruch,[35] that is, "carnification," because there is no inflammation with organization of the exudate, but simply an abnormal development of connective tissue especially marked in the perivascular spaces and the interalveolar septums. This connective tissue compresses the alveoli and causes an atrophy of the parenchyma of the lung, but never penetrates the alveoli. Degeneration of the mucosa, atrophy or atypical growth of the bronchial epithelium was noticed, whereas the alveolar epithelium had completely disappeared. The bronchial vessels and their finer tributaries were constantly dilated. It is thus clear that the lesions following ligation of the pulmonary arteries are quite similar to those following ligation of a bronchus. Figure 3 shows the roentgenographic evolution after ligation of the left pulmonary artery. It pictures the striking similarity between the results obtained after suppression of circulation on the one hand and suppression of ventilation on the other, as in cases of obstructive atelectasis. Comparison should be made with our roentgenograms of atelectasis (figs. 10, 12, 14 and 16). The shrinkage of the involved lobes is shown clearly in figures 3 and 4.

Schlaepfer kept dogs with ligated pulmonary arteries for two years. He found the collateral nutritive circulation well established within two months after ligation or within three months in dogs in which he sectioned the phrenic nerve at the same time. The caliber of the bronchial artery is doubled within that period, and from three to four times its normal caliber within two years.

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46. Küttner (footnote 38, first reference).

47. Kawamura, K.: Ueber die künstliche Erzeugung von Lungenschrumpfung durch Unterbindung der Pulmonarterienaste, Deutsche Ztschr. f. Chir. **125**:373, 1913.

48. Ritter and Ostrowsky, quoted by Smirnoff (footnote 45).

Ligation of the pulmonary vein of a lobe is followed by different results than is ligation of a corresponding artery. As Smirnoff [49] has shown, the return circulation to the left side of the heart will be completely suspended, so that the blood in the bronchial and pulmonary capillary systems can return only by way of the bronchial veins and so through the azygi, intercostal veins and superior vena cava back again to the right side of the heart. If these collaterals are sufficient, the return circulation might be unimpaired. In the dog these anastomoses are insufficient, and ligation of the pulmonary veins is followed by

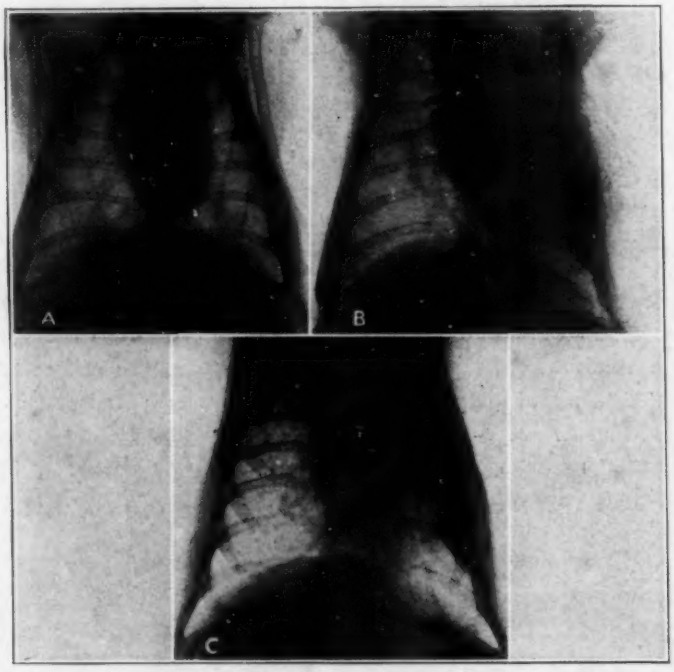

Fig. 3.—*A*, normal rabbit's chest. The position of the mediastinum and the heart may be noted. *B*, rabbit chest fifty-seven days after ligation of the left pulmonary artery combined with resection of the phrenic nerve. Silver clips were applied to the nerve. Displacement of the mediastinum and the heart toward the side on which operation was performed may be noted. Cloudiness is seen in lung area on the opposite side. The light area in the lower left side resulted from the displacement of the right mediastinal lobe, interposed between the diaphragm and the left lung. *C*, the same chest after 110 days. Displacement of the mediastinum is more marked. Gradual dilatation of the right mediastinal lobe caused an enlargement of the light area in the lower left region (after Schlaepfer).

49. Smirnoff, S. A.: Versuche über einfache und kombinierte Unterbindung der Lungengefässe, Arch. f. klin. Chir. **146**:215, 1927.

lethal complications, that is, stasis, passive congestion and edema. It is interesting to note what happens in partial occlusion of the pulmonary veins in the dog when survival of the animal is possible. Schlaepfer [50] ligated the left pulmonary veins in thirteen dogs so as to decrease the diameter to one-fourth the original.

> Dogs may die during or shortly after the reduction of the size of the pulmonary vein in from one to two days after operation with increasing dyspnea, congestion, hemorrhages into the lung and dilation of the right ventricle. . . . If the animal survives the acute effect of the operation, complete recovery occurs within forty-eight hours and he remains quite well.

The lung with veins reduced in diameter become smaller than the lung that has not been operated on. A collateral venous circulation is gradually developed in the former through pleuropulmonary adhesions;

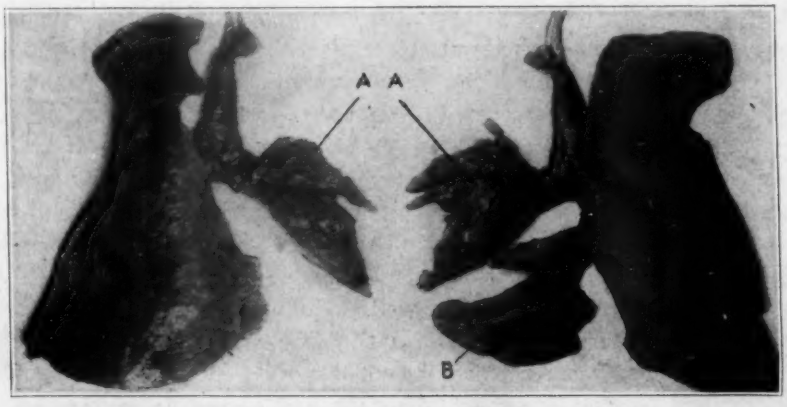

Fig. 4.—Rabbit lung 109 days after ligation of the pulmonary artery combined with phrenicotomy. On the left is the anterior aspect; on the right, the posterior aspect. The small shrunken left lung may be noted. The right mediastinal lobe shows a compensatory dilatation; *A*, shrunken left lung; *B*, right mediastinal lobe (after Schlaepfer).

the bronchial veins are greatly increased in size. Schlaepfer [51] has already shown the clinical importance of this compensatory circulation. The capillaries of the lung that has not been operated on are dilated and

50. Schlaepfer, K.: Morphological Changes Associated with Partial Occlusion of the Pulmonary Veins of One Lung, Surg. Gynec. Obst. **42**:679, 1926; Collateral Circulation Following Chronic Obstruction of the Pulmonary Veins and Its Relation to Air Embolus Following Various Diagnostic and Therapeutic Procedures (Pneumolysis), ibid. **37**:510, 1923; Fibrosis of the Lung Following Ligation of the Pulmonary Artery: Combined with Phrenicotomy and with Partial Occlusion of the Pulmonary Veins, Arch. Surg. **6**:358 (Jan.) 1923.

51. Schlaepfer, K.: Ligation of Pulmonary Artery of One Lung with and without Resection of the Phrenic Nerve, Arch. Surg. **9**:25 (July) 1924; footnote 44.

the diameter of the pulmonary artery is greater than on the side on which the operation has been performed. The hemorrhages in the alveoli of the lung that has been operated on gradually disappear, and an irregularly distributed fibrosis is noted.

On the contrary, simultaneous ligation of the pulmonary artery and vein in dogs is well tolerated, the bronchial vessels being able to insure the nutrition of the lung. Smirnoff [49] concluded that in cases of accidental injury of an important branch of the pulmonary vein in man, necessitating its ligation, it is far better to ligate the corresponding branch of the pulmonary artery as well. In dogs with simultaneous ligation of a lobar pulmonary artery and vein, the lung was found shrunken and airless in from five to seven weeks after operation. Microscopically, there was hypertrophy of connective tissue with atrophy or destruction of the respiratory epithelium as in ligation of the artery alone. The nourishment of the lobe is assured by the bronchial vessels, which through their anastomosis with the pulmonary venous capillaries supply enough blood to the alveoli. There is a "reduced circulation" sufficient, however, to keep the atelectatic and inactive lung alive.

Ligation of bronchial vessels is technically difficult because of their multiplicity of origin and anastomosis with the esophageal, mediastinal, pericardial and intercostal arteries (Bruns and Sauerbruch [52]). Smirnoff [49] ligated the bronchial vessels en masse on a bronchus. The animals withstood this operation well. No marked changes resulted in the lung. After thirty-two days the lobe was found to be little decreased in size, was aerated and floated readily in water.

Combined ligation of bronchial vessels and corresponding branches of a pulmonary artery leads to gangrene of the lung. The same result is obtained by combined ligation of bronchial vessels and the corresponding branch of the pulmonary vein.

The foregoing description of the physiology of the circulation of the lung, the relations between the pulmonary and bronchial systems and the absence of necrosis or hemorrhage in cases of occlusion of the pulmonary artery seem in contradiction to the production of hemorrhage which is the outstanding feature described in embolic obstruction of a branch of the pulmonary artery. This discrepancy is only apparent. As pointed out by Karsner and Ash:[53] "Hemorrhage is a secondary process . . . it is found but rarely unless some com-

52. Bruns, O., and Sauerbruch, F.: Die künstliche Erzeugung von Lungenschrumpfung durch Unterbindung von Asten der Pulmonarterie, Mitt. a. d. Grenzgeb. d. Chir. **23**:343, 1911.

53. Karsner, H. T., and Ash, J. E.: Studies in Infarction, J. M. Research **22**:205, 1927.

plicating condition is present." Grawitz [54] went so far as to deny the embolic origin of lung infarction, but the work of Fujinami,[55] Orth [56] and of Zahn [57] showed definitely the causative relation between embolism and an infarct. Zahn first drew attention to the fact that passive congestion increased the chances for infarction. Karsner and Ash [58] came to the conclusion that simple bland embolism of the pulmonary artery produces circulatory changes in the lung area supplied, but not a true infarction, unless there is a previous passive congestion; in the presence of an already existent embolism in the lobe, ligation of the pulmonary vein of that lobe leads to the formation of a true infarct.

INNERVATION OF THE PULMONARY VESSELS

For the sake of completeness, we must consider here the question of innervation of the pulmonary vessels which is at present in an utterly confused state. As Cloetta remarked in 1914,[58] "Notwithstanding the voluminous literature upon the subject we know nothing about the existence of vasomotors in the vessels of the lung." The recording of pulmonary artery pressures is insufficient to solve the problem because of their wide variations due to the influence of lung movements on the lesser circulation. Tigerstedt [59] and Krogh [60] thought that vasoconstrictor fibers existed in the vagus. By electrical irritation of the vagus in a turtle, Krogh [61] observed a decrease in the output from the pulmonary veins on the same side. These observations have not been verified. Later (1922), Krogh [62] admitted that "this question is still open." Baehr and Pick,[63] after much experimental work, concluded that none of the toxic substances that have a bronchoconstrictor or bronchodilator effect on the lung produces even the slightest modification in size of the lung vessels. Weber,[3]

54. Grawitz, P.: Ueber die hemorrhagischen Infarkte der Lunge, Festschrift der Assisten von R. Virchow, Berlin, 1891.

55. Fujinami, A.: Beitrage zur Entstehung der hermorrhagischen Infarkte der Lunge, Virchows Arch. f. path. Anat. **61**:152, 1898.

56. Orth, J.: Ueber experimentelle Erzeuge der hemorrhagischen Infarkte der Lungen, Verhandl. d. Gesellsch. deutsch. Naturf. u. Aerzte **69**:7, 1897.

57. Zahn, F. W.: Ueber die Folgen des Embolie Verschlusses der Lungenarterien und Pfortaderaste durch Embolie, Verhandl. d. Gesellsch. deutsch. Naturf. u. Aerzte **69**:9, 1898.

58. Cloetta (footnote 1, second reference).

59. Tigerstedt, R.: Ueber den Lungenkreislauf, Skandin. Arch. f. Physiol. **14**:259, 1903.

60. Krogh (footnote 32, first reference).

61. Krogh, A.: The Regulation of the Supply of Blood in the Right Side of the Heart, Skandin. Arch. f. Physiol. **27**:227, 1912.

62. Krogh (footnote 32, second reference).

63. Baehr, G., and Pick, E. P.: Beiträge zur Pharmakologie der Lungenfefässe, Arch. f. exper. Path. u. Pharmakol. **74**:65, 1913.

using an oncometer, concluded that vasoconstrictors were present. Cloetta and Anderes [58] investigated the same subject in cats, rabbits and dogs anesthetized with urethane, paraldehyde, bromdiethylacetamid and ether; in a few cases curare was given. The chest was opened, the common bronchus of the left lung ligated and the right lung placed in the plethysmograph. Oxygen under a constant pressure of 2.5 cm. of water was given through a double tracheal cannula going to the bifurcation of the trachea. The pressures of the pulmonary artery, of the carotid and of the tracing of the plethysmograph, were recorded on the same drum. It is obvious that any slight elevation occurring simultaneously in the curves of the plethysmograph, the pulmonary artery and the carotid would indicate an increase in intrapulmonary blood flow due to increased pressure in the great circulation. This is exactly what happens on intravenous injection of epinephrine, which is without effect on the lung vessels (Cloetta and Anderes [58]).

However, using a substance related to histamine (B. imidoazolylethylamine), Cloetta [58] claimed to have produced strong vasoconstriction of the pulmonary capillaries by the intravenous injection of 1 mg. into the cat; this vasoconstriction is shown by the sudden rise in the pulmonary artery pressure, fall of the plethysmographic curve and an unchanged pressure in the carotid; this would seem to demonstrate the existence of vasoconstrictors. Dale and Laidlaw [64] agreed with Cloetta; [58] but Weber,[65] experimenting with the same substance, noticed vasodilation of the lung vessels, and Baehr and Pick [63] observed no effect. Starling [66] considered that the action of vasomotor nerves is "of little importance and their very existence is questioned by some observers . . . Changes in the calibre of the lung arterioles play under normal conditions, very little part in determining the pressure; on the other hand, considerable changes in the pulmonary pressure are induced by altering the inflow into the right heart and thereby the velocity with which the blood must be propelled through the pulmonary artery and the carotid would indicate an increase in if any, are described as running in the anterior roots of the third, fourth and fifth thoracic nerves. It is generally agreed that no vasomotor nerves of the lung are to be found in the vagi. Fontaine and Herrmann [67] showed that in the dog, a unilateral section of the first four

64. Dale, H. H., and Laidlaw, P. P.: B-Iminazolylethylamine, Action on the Pulmonary Vessels, J. Physiol. **41**:325, 1910-1911.

65. Weber, E.: Entgegnung auf die Abhandlung von M. Cloetta: "Besitzen die Lungen Vasomotoren?" Arch. f. Anat. u. Physiol., Suppl., 1914, p. 532.

66. Starling: Principles of Human Physiology, p. 855.

67. Fontaine, R., and Herrmann, L. G.: Experimental Studies on Denervated Lungs, Arch. Surg. **16**:1153 (June) 1928.

thoracic sympathetic ganglions, combined with removal of the ansa of Vieussens and the stellate ganglion together with the resection of that portion of the vagosympathetic trunk included in the middle cervical ganglion, does not cause any disturbance in the function of the lung which reacts to all forms of stimulation in the same way as the opposite lung.

We have thus seen that the existence of vasomotor nerves to the lung vessels, either as extrinsic or intrinsic fibers, as well as the problematic question of their physiology, has so far not been proved.

It is evident with how complicated a subject we are dealing, being, as it is, so closely connected with the physiology of circulation in the lung. Under these conditions it is obvious how hazardous it is to assign the pathogenesis of atelectasis to "reflex irritation," "vasomotor reflex" or to "angioneurotic edema" as a number of authors still do. We have insisted on this point in previous papers.

The physiologic and anatomic data already given will render easier the disentanglement of the complicated question of circulation in the atelectatic and pneumonic lung.

CIRCULATION IN THE ATELECTATIC (APNEUMATIC) AND COLLAPSED LUNG

The problem of the relation existing between respiration and blood flow in the lungs is as important as it is complicated. It is important because its exact knowledge will be of great help to the thoracic surgeon who by the mere opening of the thoracic cavity, with consequent collapse of the lung, produces great alterations in the lesser circulation which are still incompletely known factors in the operative results. Fully 75 per cent of the deaths resulting from thoracic operations are due to circulatory troubles. The use of differential pressure (Sauerbruch,[2] Friedrich and Brauer, quoted by Sauerbruch), artificial pneumothorax, phrenicectomy, thoracoplasty, ligation of branches of the pulmonary artery or even respiration in hypopressure makes knowledge concerning their physiology necessary.

The problem is complicated because other factors besides respiration exert their influence on the lesser circulation, as for example, the pressure on and output from the left side of the heart, the action of the negative intrapleural pressure on the big vessels and the heart, the changes in length of the pulmonary capillaries, the movements of the diaphragm, etc.

Although the controversy started in 1855, there is not as yet to be found in the literature a definite answer to the question whether a collapsed and atelectatic lung contains more blood than the healthy one or even whether the blood flow is greater on expiration or on inspi-

ration. We think it advisable to give an historical analysis, as complete as the scope of this work allows, of the previous relevant investigations.

Poiseuille [68] appears to be the first to have experimentally studied the question in his effort to discover the reasons for the production of the successive respiratory movements, that is, inspiration and expiration. He studied the capacity of elastic capillary tubes when their length was varied and found that if their length is increased their diameter and their capacity decrease. By injecting both collapsed and insufflated lungs with a gelatin mass, he found in microscopic sections that the capillaries were smaller in the insufflated than in the collapsed lobes. In perfusing collapsed and insufflated lobes of the same lung, he noticed that a given volume of fluid passed through the collapsed lobes more quickly (3 cc. in one minute and twenty seconds) than through the moderately insufflated ones (3 cc. in one minute and fifty-nine seconds); in the greatly distended lobes, the 3 cc. required two minutes and nineteen seconds for passing through. In observing the circulation in the frog's lung under the microscope, he found that the red cells circulated more rapidly when the lung was collapsed than when it was insufflated. Donders,[69] on measuring the intrapulmonary pressures, came to similar conclusions (1858-1859). These two authors believed that on inspiration the capillaries were narrowed and that on expiration they were dilated; according to them, in the collapsed lung this dilatation was even more marked.

Quincke and Pfeiffer,[70] Funke and Latschenberger,[71] Bowditsch and Garland,[72] among the early investigators, accepted Poiseuille's [68] views. On the contrary, Lichtheim,[73] d'Arsonval,[74] Zuntz,[75] de Jager,[76]

68. Poiseuille: Recherches sur la respiration, Compt. rend. Acad. d. sc. **4**: 1071, 1855.

69. Donders, F. C.: Weitere Beiträge zur Physiologie der Respiration und Circulation, Ztschr. f. rationelle Med. **4**:241, 1853; Beiträge zu Mechanismus der Respiration und Circulation in gesunden und kranken Zustande, ibid. **3**:289, 1853.

70. Quincke and Pfeiffer: Ueber den Blutstrom in den Lungen, Arch. f. Anat. u. Physiol., 1871.

71. Funke, O., and Latschenberger, J.: Ueber die Ursachen der respiratorischer Blutdurck-Schwankungen in Aortensystem, Arch. f. d. ges. Physiol. **15**:405, 1877.

72. Bowditsch, H. P., and Garland, G. M.: The Effect of the Respiratory Movements on the Pulmonary Circulation, J. Physiol. **2**:91, 1879.

73. Lichtheim, L.: Die Störungen des Lungen kreislaufs und ihr Einfluss auf den Blutdrück, Berlin, 1876.

74. D'Arsonval, A.: Recherches theoriques et expérimentales sur le rôle de l'élasticité du poumons dans les phénomènes de la circulation, Thèse de Paris, 1877.

75. Zuntz, N.: Beiträge zur Kentniss der Einwirkungen der Atmung auf den Kreislauf, Arch. f. d. ges. Physiol. **17**:374, 1878.

76. De Jager, S.: Ueber den Blutstrom in den Lungen, Arch. f. d. ges. Physiol. **20**:426, 1879.

Heger [77] and Heger and Spehl [78] arrived by different experimental methods at diametrically opposed conclusions; namely, that in the normally inflated lung the capillaries are dilated, that on expiraion and in the collapsed lung they are narrowed, and that for these reasons the blood flow in and the blood capacity of the lung are much greater in the expanded lung. Bernstein,[79] in studying the intrapleural negative pressure in new-born children, found that the negative intrapleural pressure which is absent in stillborn children can easily be produced by the insufflation of the lungs, because the thorax after insufflation of the lungs does not come back to its previous position but remains somewhat expanded. Hermann [80] explained this phenomenon by the fact that after the insufflation or the first inspirations have overcome the resistance of the alveolar walls which are in contact, the alveoli do not completely collapse again, because at the same time the capillaries of the lung dilate, and the lung which in the fetal state received a very small amount of blood now absorbs the total content of the right ventricle. This change in the pulmonary circulation has as a result the gradual closing off of the two short cuts by which the right side of the heart communicated with the left side and the aorta, namely, the foramen ovale and the ductus arteriovenosus. We shall later return to this important point, the significance of which, we think, has not been sufficiently stressed.

The studies on the disturbances caused by pneumothorax to the circulation and respiration, by Hnatek,[81] Gilbert and Roger,[82] Arnolds,[83] Aron,[84] Blumenthal,[85] Kreps,[86] Lieven [87] and especially by Sackur,

77. Heger: Recherches sur la circulation du sang dans les poumons, Brussells, 1880.

78. Heger and Spehl: Recherges sur la fistule péricardique, Arch. de biol., 1881.

79. Bernstein, J.: Ueber die Entstehung der Aspiration des Brustkorbes bei der Geburt, Arch. f. d. ges. Physiol. **17**:617, 1878.

80. Hermann, L.: Ueber den atelectatischen Zustand der Lungen und dessen Aufhoren bei Geburt, Arch. f. d. ges. Physiol. **20**:365, 1879.

81. Hnatek: Untersunchungen über die Störungen des Blutkreislaufs und der Atmung beim pneumothorax, Allg. Wien. med. Ztg., 1898, p. 267.

82. Gilbert and Roger: Etude expérimèntale sur le pneumothorax et sur les réflexes d'origine pleurale, Rev. de méd., no. 233, Nov. 12, 1891, p. 122.

83. Arnolds, A.: Ein Fall von Pneumotomie wegen Fremdkörper ehe Eiterung eingetreten, Mitt. a. d. Grengeb. d. Med. u. Chir. **4**:251, 1899.

84. Aron, E.: Experimentelle Studien über den Pneumothorax, Virchows Arch. f. path. Anat. **145**:562, 1896.

85. Blumenthal: Experimentelle Untersuchungen über den Lungengaswechsel bei den verschiedenen Formen des Pneumothorax, Ges. Abhandl. a. d. med. Klin. zu Dorpat, Wiesbaden, 1893.

86. Kreps: Ueber die Atmungsbewegungen bei den verschiedenen formen des Pneumothorax, Ges. Abhandl. a. d. med. Klin. zu Dorpat, p. 413, 1891.

87. Lieven: Ueber den Blutdruck bei den verschiedenen Formen des Pneumothorax, Dorpat, 1893.

gave a new impetus to further experimental and clinical study. Interest was further aroused because of the advances accomplished by the pioneer thoracic surgeons, Quincke,[88] Garre and Sultan,[89] Reclus,[90] Matas,[91] Tuffier and Hallion,[92], etc.

In 1904, there appeared the epoch-making paper of Sauerbruch,[2] which marks the beginning of a new phase in the already lengthy discussion of the question. Sauerbruch made a distinction between a lung compressed with, or collapsed without, pneumothorax. He believed that in the lung collapsed without open pneumothorax, where it is in "normal relation with the pleural cavity," the cross-section of the capillary systems is decreased, so that in it "both respiration and circulation are impaired." The lung of the other side undergoes a compensatory distention because "the respiratory increase in the healthy lung, which regularly occurs, is accompanied by an increase in its capillary blood capacity; more blood passes through it, so that notwithstanding the decrease in total respiratory surface, the sound lung can suffice for oxygenation of the blood." He further maintained that in that case there is on inspiration an increase and on expiration a decrease in the blood flow.

But in the collapsed and compressed lung with open pneumothorax, according to Sauerbruch, the circulatory conditions are different. "In unilateral pneumothorax," he said, "more blood passes through the collapsed lung in a unit of time than before establishment of a pneumothorax." He based this conclusion on the experimental observations of Poiseuille,[68] Quincke and Pfeiffer,[70] and particularly of Sackur. The latter author, by analysis of the oxygen and carbon dioxide content of the blood from the carotids, before and after pneumothorax, had come to the conclusion that "because of the great dilation of the capillaries of the affected lung, much more blood passes through it than through the sound one, which explains cyanosis and dyspnea." This is in essence the "short circuit" theory.

There seems, however, to be a contradiction here; if collapse of the alveoli produces dilatation of the capillaries, how is it that in the healthy hyperdistended lung there is an increase of blood? As it is of such crucial importance to establish whether Sauerbruch's contentions are correct,

88. Quincke, H. I.: Ueber die Pneumotomie, Mitt. a. d. Grenzgeb. d. Med. u. Chir. **1**:1, 1896.

89. Garre, D., and Sultan, C.: Kritischer Bericht über 20 Lungenoperationen, Beitr. z. klin. Chir. **32**:492, 1901-1902.

90. Reclus, P.: La chirurgie du poumon, Rev. de chir. **15**:871, 1895.

91. Matas, R.: The Management of Acute Traumatic Pneumothorax, Ann. Surg. **29**:409, 1899.

92. Tuffier and Hallion: Operation intrathoraciques avec respiration artificielle par insufflation, Compt. rend. Soc. de biol. **48**:951, 1896.

we must dwell on this point yet a while. Sauerbruch claimed the blood flow through the lung was dependent on four fundamental factors: (1) the strength of the right side of the heart, (2) the difference between the pulmonary artery and pulmonary vein pressures, (3) the intrapulmonary pressure and (4) the changes in the diameter of the capillaries following the changes in the volume of the lung. Assuming that the strength of the right side of the heart is constant, with each inspiratory phase there will be an increase in the negative pressure and suction on the thin-walled pulmonary veins and accordingly an increase of the difference in pressures between the pulmonary arteries and veins, as well as a decrease in pressure of the intrapulmonary air; consequently, there will be an expansion of the lung vessels with an increase in their diameter and capacity and an increased blood flow through the lungs. Furthermore, increased negative intrapleural pressure and the suction thus exerted on the big intrathoracic vessels (on the thin-walled veins much more than on the arteries) will have as a direct result an increase in the blood flow from the peripheral veins to the right side of the heart, so that during inspiration the heart will receive more blood in diastole and send more blood in systole than during expiration. Under other conditions, as, for example, on expiration, less blood will come to the right side of the heart and less will leave the left side. Sauerbruch gave the mechanism described and concluded: "The result of these continued causes on inspiration is an increased blood flow in the lungs."

During expiration, several factors contribute to give an opposite effect. These are, according to Sauerbruch, the decrease of the negative intrapleural pressure, the decrease of differential pressure between the pulmonary arteries and the veins, the contraction and decrease in the size of the lung capillaries and, as a result, a decreased flow of blood through the lung.

It is peculiar how, after the foregoing concepts, Sauerbruch [2] added that "in open pneumothorax an equalization occurs in the pressures exerted inside and outside of the lung, which will have as a result: the further decrease in the difference of pressures between pulmonary arteries and veins, and further that the lung capillaries will be under a steady and unchanging pressure of one atmosphere, and so they will be increased in size in such a way that in open pneumothorax more blood will pass through the collapsed lung than before the establishment of the pneumothorax, and even more than through the sound lung." Such a contention is peculiar, because if, as in expiration, the decrease in difference between intrapulmonary and intrapleural pressures produces a decrease in the flow of the blood through the lung, how can the still further decrease in this difference (in pneumothorax) produce an opposite effect, namely, an increase in the blood flow?

The dyspnea in unilateral pneumothorax would be due, according to Sauerbruch, to the greater part of the blood circulating through the unaerated channels of the collapsed lung and going back to the left side of the heart nonoxygenated. Against Sauerbruch's theory, a great number of arguments can be gathered from his own paper.[2] On measuring the respiratory air per minute in rabbits before and after unilateral open pneumothorax, he found that after a first period of adjustment in which the number of respiratory movements is increased, the respirations come back to a normal rate with the difference that they become deeper, exactly as after section of one or both vagi. We give here a few of his experimental results (page 413).

1. Rabbit 2,100 Gm. Immediately after Pneumothorax

	Volume of Air per Minute		Number of Respirations	
1st phase	Normal	1. pneumothorax	Normal	1. pneumothorax
	480	530	58	74

2. Rabbit 2,400 Gm. Ten Minutes after Pneumothorax

	Volume of Air per Minute		Number of Respirations	
2d phase	Normal	1. pneumothorax	Normal	1. pneumothorax
	460	470	54	48

The same effects occur if the vagi are sectioned, and Sauerbruch expressed the belief (page 416) that "the stimulation from the lung to the respiratory centre fails in pneumothorax because of the inactivity of the collapsed lung, as also in vagotomy because of the interruption of the nervous connections." We believe it is clear that if the cause of the dyspnea is the increase in carbon dioxide content of the blood, dyspnea should not cease after from two to ten minutes. That dyspnea does disappear would indicate rather that there is no longer an increased carbon dioxide content of blood, which can occur only if the blood is completely diverted from the collapsed lung to the sound one. Another fact against Sauerbruch's views is the remark he made (page 418) that if after the establishment of a mild open pneumothorax one artificially inflates the collapsed lung and clamps the bronchus, the dyspnea ceases immediately. The explanation Sauerburch gave for this phenomenon is that "all other conditions remaining the same as in open pneumothorax, except the change in volume of the lung, we must admit that the decrease in size is the cause of dyspnea," and "this decrease in size produces the dyspnea by the dilation of the capillaries." We cannot agree with this last statement because in both cases—open pneumothorax with patent or clamped bronchus—the lung is unaerated and the causes of nonoxygenation of the circulating blood are the same (assuming that the blood vessels were

not clamped with the bronchi). We think it is apparent that the absence of dyspnea in the experiment with inflated lung and clamped bronchus is due to the fact that there is no sudden collapse and sudden extra burden thrown on the right side of the heart, as occurs in sudden suppression of the circulation in the collapsed lung. The cause of this temporary dyspnea is to be sought for particularly in the disturbance of the heart.

We do not believe that Sauerbruch is correct in his conception. It would seem that he was forced to it because he considered as definitely proved the conclusions of Poiseuille, Quincke and Pfeiffer, etc., concerning the dilatation of capillaries in the collapsed lung. He was especially influenced by the work of Sackur, who found that in open pneumothorax the arterial blood contained more carbon dioxide and less oxygen than before. It should be mentioned here that Sauerbruch himself later modified (1926) his conception and admitted that his former views were not beyond debate.

In our opinion, the capillaries in the collapsed and atelectatic lung are collapsed proportionately to the shrinkage of the lung with a consequent and proportionate impairment of circulation through the lung.

Cloetta and his collaborators upheld Sackur in his views. Cloetta performed a series of brilliant experiments with the plethysmograph that he invented for the purpose, and came to the following conclusions (1911):

> The study of the plethysmographic pulsations of the lung, of the changes of pressure in the carotid, of the pulsations of the right ventricle, of the chemical analysis of the blood and of microscopic sections of inflated and collapsed lung, leads to the conclusion that the hematosis of the lung is better on expiration than on inspiration.

In a more recent paper, Cloetta and Anderes [58] "determined with the greatest possible accuracy the changes in the lung circulation by recording at the same time plethysmograms of the lung and the pressures in the carotid and pulmonary arteries, in a completely closed gas system." In this paper, Cloetta concluded that "the circulation is incomparably better in the collapsed lung than in the healthy lung."

The opposite point of view is upheld by Bruns.[5] In a remarkable paper, he exhausted the subject of circulation in the collapsed and atelectatic lung and gave a thorough discussion of the work of Cloetta, whose conclusions he does not accept. Bruns [5] said:

> In the breathing and normally distended lung, the volume and flow of blood are proportionate to the degree of expansion of this organ; . . . In the collapsed lung, the more pronounced the degree of airlessness, the smaller is the blood volume and velocity—and this independently of the cause and mechanism of the collapse (or atelectasis) of the lung.

According to Bruns,[5] the foregoing conclusions hold for every kind of atelectasis (obstruction of a bronchus, fluid or air in the pleural cavity, or even chronic retraction of the lung). In a general way, he concluded, hematosis is far better on inspiration than on expiration.

If Poiseuille,[68] Quincke and Pfeiffer,[70] and Funke and Latschenberger [71] came to opposite conclusions, this was due to the fact that they used to inflate the lung extracted from the chest with air introduced through the trachea. It is known that the blood pressure in the pulmonary vessels is very low, owing to the small resistance offered by the lung capillaries. According to Sauerbruch,[35] it is only from 20 to 30 mm. of mercury, so that in the lung out of the chest, with intrapleural negative pressure removed, it is easy to understand that a combination of atmospheric pressure from without and intrapulmonary insufflation from within can compress the capillaries.

Other experimenters tried to study the capacity of the lung capillaries during inspiratory distention and expiratory deflation by the modifications observed in the systemic blood pressure and the pulse. Unfortunately, a great number of conflicting factors, already enumerated, render the results thus obtained unreliable. Bruns used a direct method in his determinations of the respective blood capacities of the sound and collapsed lungs. He determined colorimetrically the amount of blood contained in the respective lobes and found that the volume of blood in the collapsed lung is regularly smaller, and that this decrease in volume is proportionate to the degree of airlessness of the collapsed lung. Other important points to be determined were: (1) the volume of the blood circulating through the lung vessels during inspiration (with chest intact) but with the heart not subjected to the intrapleural negative pressure; (2) the blood velocity during normal expansion of the lung, with heart and big vessels subjected to the action of the negative intrapleural pressure; (3) the blood velocity in the very expanded lung, the body of the animal being subjected in a closed space to hypopressure (— 20 to — 30 cm. of water); (4) the velocity of the blood with normal expansion of the lung but under intrapleural hypopressure; (5) the velocity with one lung collapsed, and (6) the velocity with both lungs collapsed.

Bruns answered these questions by skilfully conducted experiments on rabbits. Three-hundredths gram of hirudin was injected by vein, the second, third and fourth ribs were resected close to the sternum and the anterior mediastinum was opened; this can be done in the rabbit without opening the pleural cavities. The heart was displaced out of the chest. A cannula was placed in the trachea and the animal killed by a blow on the neck. Another cannula was rapidly inserted into the origin of the pulmonary artery, and another in the left ventricle, avoiding the entrance of air. The heart was returned to the pericardial

sac again and the animal placed in an airtight box. The three cannulas, tracheal, pulmonary artery and cardiac, were connected to tubes passing through the walls of the box. The cannula of the pulmonary artery was connected with a bottle containing defibrinated rabbit's blood placed 30 cm. above the level of the animal's chest. The results can be summarized as follows: In overdistention of the thorax by extrathoracic hypopressure of —30 cm. of water, neither narrowing of the lung capillaries occurs nor an increase in the blood flow through the lungs. On the contrary, by lowering the intrapulmonary pressure the amount of blood circulating through the lungs is markedly increased. These conclusions are in opposition to Cloetta and Anderes' observations.

Bruns [5] objected to Cloetta's interpretation of his pulse curves obtained for the lung (collapsed and inflated) enclosed in the plethysmograph. Cloetta [93] found that the pulsations of the collapsed lung were much stronger than those of the inflated lung. He explained that by the greater possibility of the blood vessels in the collapsed lung to straighten out from their more or less crooked and tortuous state, whereas in the inflated lung the vessels were already straight and so less apt to have their configuration influenced by the pulse waves. To Cloetta,[93] this was an indirect proof that the vessels were elongated in the inflated lung; he concluded that because of this the blood flow through it was decreased. We have previously seen that elongation of the vessels does not necessarily decrease their capacity. Moreover, Bruns [5] has shown that the height of the pulsations in Cloetta's experiment does not depend on the volume of blood flow, but principally on the concomitant degree of tension within the lung tissue. In order to prove this, Bruns used a special closed glass cylinder containing a thin rubber tube. The pressure within the glass cylinder could be varied, and through the tube a suction and pressure pump sent in with each movement of the plunger exactly the same amount of water; these "pulsations" of the tube were recorded on a kymograph by varying the pressure exerted on the rubber tube from —10 cm. to + 2 cm. of water. Bruns [5] obtained a decrease in the magnitude of pulsation on hypopressure, and an increase on hyperpressure. Bruns [5] thus contended that the magnitude of plethysmographic pulsations is not closely related to or dependent on the blood flow but is proportional to the degree of distention of the lung tissue; and in this conception Tendeloo concurred.

Mathes and his collaborators [94] found that when water was circulating in a thin rubber tube, the pressure required to compress the

93. Cloetta (footnote 1, first reference).

94. Mathes, M.; Quenstedt; Gottstein, and Dahm: Einige Beobachtungen zur Lehre vom Kreislauf in der Peripherie, Deutsches Arch. f. klin. Med. **89**:381, 1906-1907.

tube and stop the flow was proportionate to the velocity of the current within it. The conclusion to be drawn from these two experiments is that the magnitude of pulsation of a lung enclosed in a plethysmograph varies according to the internal and external pressures exerted on the walls of the vessels. With inspiratory enlargement of the lung, the volume variations of the vessels and the amplitude of the tracings decrease, whereas the blood flow increases; this is so because of the concomitant dilatation of the vessels and the action of the pulmonary elastic tissue surrounding the vessels, which is stretched on inspiration. To state this in another way, the increased blood velocity, by causing a rise in the pressure exerted on the vessels from within, diminishes their oscillatory capacity. From the size of the pulse wave as recorded in a plethysmograph tracing, no accurate conclusions can be drawn concerning either performance of the heart or volume of the blood flow through the lung. Only the rise or fall of the plethysmographic curve as a whole can give us some information as to the blood volume of the lung. This curve rises on inspiratory inflation of the lung and falls on expiratory collapse, indicating that Cloetta's views are incorrect.

To the impartial observer, Bruns [5] said it seems altogether inexplicable why precisely at the moment the lung is inflated so as to contain the maximum amount of oxygen the blood flow through the vessels should be reduced to a minimum, and conversely, be increased when the lung contains a minimum of oxygen. What then, would be the reason for supplementary inflation of the lung when the other is collapsed, resected or plugged, and how could the regulation of oxygen and absorption of carbon dioxide remain so constant? The results of Bruns [5] corroborate the observations of de Jager [95] and correspond to the figures given by Heger and Spehl,[78] who found that at the height of inspiration the lungs contain one twelfth of the total volume of blood, whereas at the end of expiration they contain only one eighteenth of the total volume.

Straub,[96] using the heart-lung preparation of Starling, tried to determine: (1) the relation of the blood pressures at different points of the circulatory system by graphs taken simultaneously of the right auricle, the right ventricle, the pulmonary artery, the left auricle, the left ventricle and the aorta; (2) the volume of blood flowing through a definite cross-section of a vessel in a unit of time; (3) the degree of dilatation of the alveoli, the internal pressure exerted on their inner surface and the pressure on their pleural surface, and (4) the degree of

95. De Jager, S.: Die Lungencirculation und der arterielle Blutdruck, Arch. f. d. ges. Physiol. **27**:152, 1881; footnote 76.

96. Straub, H.: Ueber die kleine Kreislauf. Der Einfluss des grossen Kreislaufs auf das Blutgehalt der Lungen, Arch. f. klin. Med. **121**:394, 1916.

dilatation of the lung in different phases of respiration. As Straub [96] remarked, the difficulty of this problem is due principally to the interrelation of the different factors and the changes invoked in the others by modifications of any one of them. Straub's conclusions are of great interest. The volume of blood flowing through the lung depends on the volume of blood expressed by the left ventricle. It depends on the aortic pressure only so far as this can modify the pressure in the left ventricle. Changes in the blood flow to the right side of the heart produce similar changes in the blood flow to the lung, in the pressure within the pulmonary artery and right ventricle. The variations in circulation through the lung produced by changes in the blood flow to the right side of the heart are comparable to those dependent on a variable arterial resistance. In pathologic conditions, however, the former factors play a more important part.

A clear explanation is thus given of the disturbances of the heart found in collapse of the lung, owing to the extra burden thrown on the right chamber because of suppression of circulation over a large pulmonary territory. The same reasoning can account for the hypertrophy of the right side of the heart following experimental pneumothorax maintained for a long time (four months, Bruns [5]). Notwithstanding the slight resistance offered by the lung capillaries and the ease with which they dilate and compensate for functional suppression of relatively large portions of lung (Lichtheim [73]), there is no doubt that chronic lesions of the lung accompanied by atelectatic alterations are followed by hypertrophy of the right side of the heart (Zuntz,[75] Gerhard [97] and Carlstrohm [98]). Weber [3] showed the changes in blood volume in the lungs of dogs, cats and monkeys under different conditions. He enclosed a lobe previously ligated (as against a patent bronchus in Cloetta's experiment) in an oncometer and registered at the same time the pressure in the pulmonary artery and aorta. Under these circumstances, the volume changes of the lung must be ascribed to changes in the volume of blood contained. Weber [3] distinguished between "passive" alterations in volume which follow closely the arterial pressure and depend on it, and "active" alterations which are independent of arterial pressure. There are two kinds of passive alterations. The first is due to the rise of resistance in the territory of the splanchnic nerves (vasoconstriction of abdominal arterioles) with a resultant increased pressure in the left ventricle and left auricle, and therefore a stasis in the pulmonary vein and a venous stasis in the lung.

97. Gerhard, D.: Beiträge zur Lehre vom Lungenkreislauf und von der mechanischen Wirkung pleuritischen Ergusse, Ztschr. f. klin. Med. **55**:195, 1904.

98. Carlstrohm, P. G.: Beiträge zur Frage der Wirkung des künstlischen Pneumothorax auf das Herz und die Zirkulation, Beitr. z. Klin. d. Tuberk. **22**: 243, 1912.

The second variety of passive alteration would be due to a rise in the arterial pressure accompanied by increase in venous pressure and increased output of right ventricle.

The active alterations are due to contraction of the lung vessels themselves. Moreover, it is possible that the right side of the heart could increase or decrease its activity independently of the left. It can, for example, contract more vigorously and so produce an active dilatation of blood vessels. In both cases an increase in the content of the blood vessels will follow. It is possible to distinguish one form from the other with certainty, for when the filling of the lung vessels is due to a rise in aortic pressure, the pressure will rise in the pulmonary artery also, whereas in the case of active dilatation of intrapulmonary vessels the pressure in the pulmonary artery will fall. Krogh [61] expressed the belief that there may even be a third form in the passive alteration of the blood volume in the lungs:

> By a rise in venous pressure, the output of the right heart will rise also and the blood stream through the lungs will be increased. Such an increase may raise the pressure in the pulmonary artery very slightly, but there can be no doubt that it must raise it and will cause distention of the pulmonary capillaries and veins. Under these circumstances it is absolutely impossible to distinguish between active and passive distension of the pulmonary vessels, except by simultaneous pressure records.

Krogh [61] criticized Weber for failing to record the pressures in the pulmonary artery, and for his assumption that "they present only very slight variations"; he concluded that the large number of volume variations recorded by Weber [99] as due to nervous stimulation and various drugs does not prove anything.

The possible compression exerted on the capillaries of the lung by intrapulmonary air is discussed by Propping [6] who remarked that the changes in intrapulmonary pressure when the glottis is open during inspiratory and expiratory phases are very slight, from +0.1 mm. of mercury to —0.1 mm. of mercury, according to the figures of Donders.[69] However,[21] on forced expiration with the glottis closed after a forced inspiration (Müller's test), or on forcing the inspiration with glottis closed after a forced expiration (Valsalva's test [100]), the intrapulmonary pressure may show wide variations; but these variations are of short duration and exert no serious influence on the capillary circulation of the lungs. In discussing the circulation in the consolidated (pneumonic) lung, we will have to deal with this question again.

Among recent authors the consensus is in favor of the view of a decreased circulation in the atelectatic lung. The suppression of the

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99. Weber (footnote 3, first reference).
100. Valsalva, A. M.: Opera, Venice, 1740.

circulation in a considerable portion of parenchyma of the lung is rapidly compensated for by the increased circulation in the intact lung. Heuer and Andrus [101] showed that after removal of one lung, or even of one lung of one side and one lobe of the other, there occurs, within a few hours, a shifting of the heart, retraction of the chest and elevation of the diaphragm of the corresponding side. The remaining lung fills the thorax completely in from four to six weeks. They followed and measured this enlargement of the remaining lobes under the fluoroscope. The capacity of the lung to dilate is great and indicates the tremendous normal reserve of respiratory surface available. Moreover, within a few hours after operation the animal was not dyspneic. Alveolar air (collected by rebreathing into a bag) and blood specimens were taken immediately; they were taken again in twenty-four hours, in three and five days after operation and thereafter at regular intervals of from several days to one month. The immediate effects were a rise in alveolar carbon dioxide and a fall in oxygen. These alveolar changes were coexistent with a temporary rise in carbon dioxide content of the blood, a marked fall in oxygen, and a rise in oxygen unsaturation. There was a compensatory marked rise in hemoglobin content of the blood and therefore of its oxygen-carrying capacity. These alterations of the alveolar air and blood carbon dioxide and oxygen content were only temporary. They were less marked twenty-four hours after operation and were back to almost normal percentages by the fifteenth day. An important observation was the compensatory increase in hemoglobin (15 per cent), and in the number of red cells (from 1,000,000 to 5,000,000).

In a more recent paper, Andrus [102] stated that collapse of the left lung by ligation of the primary bronchus produces the following immediate results: At first there is a decrease of about 42 per cent in total volume of the lung, this decrease corresponding to that following pneumectomy. The collapsed lung still contains about 30 per cent of the total cardiac output. These two factors cause a 30 per cent reduction in the carbon dioxide of the expired air, an increase in the carbon dioxide content of the arterial and venous blood and a decrease of 5.5 per cent by volume (30 per cent) in arterial oxygen content. To offset these deleterious effects, simultaneous changes of a compensatory nature occur. The respiratory volume per minute and respiratory rate are increased by about 20 per cent. The pulse rate is increased by about 14 per cent with a corresponding increase in the total cardiac

101. Heuer, G. J., and Andrus, W. de W.: The Alveolar and Blood Changes Following Pneumectomy, Bull. Johns Hopkins Hosp. **33**:130, 1922.

102. Andrus, W. de W.: Observations on the Cardiorespiratory Physiology Following the Collapse of One Lung by Bronchial Ligation, Arch. Surg. **10**:506 (Jan.) 1925.

output, and the circulation through the aerated lung is increased 60 per cent by volume per minute. Lastly, within twenty-four hours there is a marked increase in red cell count and the oxygen-carrying capacity of the blood. The blood carbon dioxide, the carbon dioxide output and the pulse rate, cardiac output and respiratory volume rate per minute return to their preoperative values about fourteen days after operation. The oxygen content of the blood remains below normal for about thirty days, while the volume per minute for the right lung remains permanently elevated. The left lung becomes completely atelectatic within three days after operation—its blood content gradually diminishes to only 8 per cent of the total cardiac output thirty-one days after collapse is established.

Two points from this paper are of particular interest:

(1) The gradual decrease in circulation in the collapsed lung; as it becomes airless the curve of decrease in the circulation through it follows closely the absorption of air for thirty-one hours. The pulmonary blood content falls from 100 to 60 per cent in the first half hour, to 50 per cent by the first hour, to 40 per cent by the fourteenth hour and to 15 per cent by the thirty-first hour. It was 8 per cent by the thirty-first day.

(2) The immediate increase by 60 per cent by volume per minute of the respiratory air. These two facts show clearly the relation between aeration and circulation in the lung, and definitely rule out the view of an increased circulation through the collapsed and atelectatic lung.

It is interesting to note the similarity between the changes following bronchial obstruction and ligation of a branch of the pulmonary artery. In both instances, collapse and then atelectasis of the corresponding lung occur (Bruns and Sauerbruch,[52] Sauerbruch,[35] Kawamura,[47] Meyer,[103] Schumacher,[104] Schlaepfer,[105] Scarff [106]). Meakins and Davies,[107] in their book on "Respiratory Function in Disease," remarked (page 26) that "if for any reason the air sacs become completely cut off from the inspired air the gases in them will not be renewed and will eventually be completely absorbed, while the blood supply by the pulmonary artery to the collapsed area will become practically nil."

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103. Meyer, W.: The Surgery of the Pulmonary Artery, Ann. Surg. **32**:189, 1913.

104. Schumacher, E. D.: Die Unterbindung von Pulmonarterienasten zur Erzeugung von Lungenschrumpfung, Arch. f. klin. Chir. **95**:536, 1911.

105. Schlaepfer (footnotes 44 and 50).

106. Scarff, J. E.: Pulmonary Blood Pressures, Arch. Surg. **12**:591 (Feb.) 1926.

107. Meakins, J. C., and Davies, H. W.: Respiratory Function in Disease, Edinburgh, Oliver & Boyd, 1925, p. 26.

Schlaepfer gave [105] a clear demonstration of these facts by detailed experiments on rabbits and dogs. In both, dyspnea follows ligation of a big branch of the pulmonary artery, but this rapidly disappears. This dyspnea, which may or may not be accompanied by cyanosis, is more marked in a mechanical obstruction or ligation of a bronchus (Lichtheim,[108] Coryllos and Birnbaum,[109] etc.); its cause is possibly a reflex transmitted thorugh the vagus. The circulatory changes in the lesser circulation are analogous. We quote the figures of Scarff: [106]

> The increase in the systolic pressure in the main pulmonary artery of a dog after ligation of the left pulmonary artery, varies from 30 to 50 per cent. The pulse pressure varies from 35 to 100 per cent. This increase in both systolic and pulse pressures persists for a number of days but eventually returns to normal. The time required is between seven and twenty-one days, fourteen days being the average time. The adjustment of the pulmonary blood pressure levels after ligation of the left pulmonary artery parallels very closely the physicochemical adjustment in the blood stream.

At autopsy are to be found, besides atelectasis of the corresponding parenchyma of the lung, a "somewhat abnormally thickened right ventricular wall and a difference in the weight ratio between the right and the left ventricle."

Yates [110] stressed the close cooperation between the respiratory and circulatory apparatus in maintaining a normal vital capacity:

> Deliveries of blood through bronchial arteries and through pulmonary arteries are controlled by the functional activities of the lungs, which are proportionate to vital capacities. . . . When the air cells are inflated the capillaries are elongated and as they carry the air cell walls with them, inflation is increased. These activities and reactions also take place in reverse order.

In order to explain this, Yates [110] cited the notion of an air-cell-capillary gear introduced by E. K. Dunham. We agree with Yates on the reversibility of the respiratory-circulatory mechanism. However, we do not very well see the necessity for further complicating the question by a consideration of an air-cell-capillary gear. Decrease in respiratory function of the lung, from whatever cause, produces an oxygen want, an increase in the amount of carbon dioxide in the blood and stimulation of the respiratory center; it increases the amplitude of respiratory movements by throwing into action the accessory respiratory muscles. The inspiratory capacity of the thoracic cavity is increased. This in turn raises the negative intrathoracic pressure and consequently favors the expansion of the alveoli. Under these conditions more blood

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108. Lichtheim, L.: Lungenatelektase, Arch. f. exper. Path. u. Pharmakol. **10**:54, 1879.

109. Coryllos, P. N., and Birnbaum, G. L.: Obstructive Massive Atelectasis of the Lung, Arch. Surg. **16**:501 (Feb.) 1928.

110. Yates (footnote 7, first reference).

will be brought to the capillaries, because of increased blood flow to the right side of the heart (suction action of increased negative pressure on the big veins), for as de Jager [95] has shown, a negative pressure acts more readily on the thin-walled pulmonary veins than on the pulmonary artery. Conversely, circulatory disturbances of the lung, from whatever cause (heart disease, hypertension, etc.), will again produce an increase of carbon dioxide, and the phenomena previously cited will be repeated. Furthermore, the production of atelectasis of the lung (without any procedure on the vessels), which limits the respiratory field of the affected portion of the lung, will be followed by a decrease in the amount of blood flow in that portion. Conversely, ligation of the pulmonary artery, without any procedure on the bronchial vessels of the corresponding portion of the lung, will produce a progressive decrease in the respiration and finally complete apneumatosis of the lobe.

In discussing the paper of Yates on "Vital Capacity in Intrathoracic Surgery," Graham mentioned his experiments with Davis [111] and the work of Chilingworth and Hopkins,[112] which are not in agreement with our views. We do not believe that the conclusions of these authors are undebatable. In the experiment of Davis and Graham, "immediately after death from ether the chest was opened and the lower lobe of each lung was removed. One of the principal blood vessels to the lobe was injected with physiological sodium chloride solution. A tight ligature was then placed around the hilum of the lobe including both the vessels and the bronchus, and the lobe was quickly immersed in 10 per cent formalin. In every instance the alveoli of the lobe whose capillaries were distended, were much smaller than those of the other lung." It is obvious that if fluid is injected into the vessels of a collapsed lung there will be produced a dilatation of the capillaries which offer but little resistance, and the capillaries will encroach on the alveolar space. In exactly the same way, with a lung removed from the chest, if the lung is insufflated under similar conditions there is encroachment on the capillaries. It was for this reason that Poiseuille,[68] Quincke [88] and Pfeiffer, and Sackur [113] and Sauerbruch [2] found that the circulation was increased in the atelectatic lung and

111. Davis, H. J., and Graham, E. A.: The Effect of Capillary Distension upon the Size of the Alveoli, to be published; quoted by Lilienthal, H.: Thoracic Surgery, Philadelphia, W. B. Saunders Company, 1920, vol. 1, p. 104.

112. Chilingworth, F. P., and Hopkins, R.: Physiologic Changes Produced by Variation in Lung Distension: II. Efficiency of the Pulmonary Circulation in Overcoming Obstruction, Am. J. Physiol. **51**:289, 1920.

113. Sackur: Zur Lehre vom Pneumothorax, Ztschr. f. klin. Med. **29**:25, 1896; Weiteres zur Lehre vom Pneumothorax, Virchows Arch. f. path. Anat. **150**:151, 1897.

decreased in the inflated lung. On the contrary, Underhill [114] had noticed a permanent dilatation in the capillaries of the intact lung, and he considered that this is due, partly at least, to the expansion of the alveoli in that lung. Experimentally, von Basch [115] showed that a system of rubber tubes wound as a slightly oblique coil about a collapsed rubber bag brought it back to expansion when the tubes were filled with water. When more water was put into the tubes they became further dilated and distended, and the bag expanded more and more; a condition similar to emphysema resulted. These observations obviously are in opposition to those of Davis and Graham.[111] Furthermore, if their interpretation were correct, then in ligation of the pulmonary artery (without ligation of the vein) expansion and not collapse of the corresponding lung would occur; for if increase in volume of the pulmonary capillaries produces shrinkage of the alveoli, a decrease in their volume should produce distention of the alveoli. Had these authors modified their experiment, this time placing the lung in a closed bell jar under a pressure of from —7 to —10 mm. of mercury, and then injected physiologic solution of sodium chloride under a pressure of +14 mm. of mercury, fixation of the lung in formaldehyde certainly would not have revealed an increase in size of the alveoli. With these precautions, approximately normal conditions would have been reproduced. The same reasoning applies to the work of Chilingworth and Hopkins.[112]

More recently, Blumgardt and Weiss [116] have studied the velocity of blood flow in normal and pathologic conditions by an ingenious method. It consists in injecting into the antecubital vein an active deposit of radium and detecting its arrival in the other arm or in the heart by a modified C. T. R. Wilson closed chamber device. In pulmonary emphysema, where the alveoli are obviously overinflated, and where, according to Davis,[111] Chilingworth,[112] and others, the capillaries should be contracted and blood flow into the lung decreased, Blumgardt and Weiss [116] found the opposite to be the case:

> Observations recorded demonstrate that even severe chronic pulmonary emphysema does not necessarily obstruct the blood flow sufficiently to interfere with normal velocity of blood flow through the lungs. On the contrary, the velocity is often increased. This increase may be an effort on the part of the

114. Underhill, S. W. F.: An Investigation into the Circulation Through the Lungs, Brit. M. J. **2**:779 (Nov. 12) 1921.

115. Von Basch: Klinische und experimentelle Studien aus dem Laboratorium Prof. Von Basch, Berlin **1**:171, 1891.

116. Blumgardt, H., and Weiss, S.: Studies on the Velocity of the Blood Flow: 1. The Method Utilized, J. Clin. Investigation **4**:1, 1927; Studies on the Velocity of the Blood Flow in Emphysema, ibid. **4**:555, 1927.

circulatory system to compensate for deficient ventilation, in which case it would be another expression of the close interrelation between the cardiovascular and ventilatory systems.

As Bruns [5] has demonstrated, an extrathoracic hypopressure of 30 cm. of water has no effect on the circulation. He said it is possible (page 482) that a strong negative extrathoracic pressure could stretch some peripheral capillaries beyond the point of elasticity, as Tendeloo [117] has shown, and bring about their narrowing. At the same time it would induce an inflation of alveoli which till then were in reserve, and the final result would be an increase in velocity and blood flow in the intrapulmonary circulation. In these experiments, however, one should remember that a strong hypopressure acts not only on the lungs but also on the heart and the systemic veins; this well known action suffices to explain the result obtained by Chilingworth and Hopkins.[112] Churchill and Agassiz [118] and Churchill [119] agreed on the interrelation between respiration and pulmonary circulation:

> A portion of lung tissue may expand with an increased volume of both blood and air encroaching upon adjacent areas of the lung, or, with a flexible mediastinum, the volume of an entire lung may become augmented, at the expense of the other side (Churchill and Agassiz [118]).
>
> It appears, therefore, that the lung by virtue of the altered dynamics of the pulmonary circuit which attends an increased rate of blood flow, is able to increase the effectiveness of its diffusable surface. This mechanism in turn helps to satisfy the increased oxygen demand usually associated with physiological increase in blood flow (Churchill [119]).

An interesting exposition of this conception is given by Franz Torek: [8]

> All matter is subject to certain physical laws and the lung is no exception. If pressure is exerted on any part of the body, for instance on the skin, there will be less blood in it. If suction is applied, the pressure thereby being diminished, the result will be more blood under the area so treated. . . . If the collapsed lung is brought into a negative pressure chamber, so that it will conform to the normal dimensions, there is an exact counterpart of the skin area mentioned before as being under the influence of suction. By thus diminishing the pressure on the outer surface of the lung, a greater amount of blood must infallibly be drawn into the organ. In the normal thorax, this condition of diminished pressure, the negative pressure on the outside of the lung, constantly exists; nature establishes it so that a maximum amount of blood may be sent to the

117. Tendeloo, N. P.: Lungengedehnung und Lungenemphysemen, Ergebn. d. inn. Med. u. Kinderh. **6**:1, 1910.

118. Churchill, E. D., and Agassiz, A.: A Method of Separating the Air Breathed by the Right and Left Lungs Together with the Effect of Pulmonary Circulatory Changes on the Divided Breathing, Am. J. Physiol. **76**:6, 1926.

119. Churchill, E. D.: The Effect of Increased Blood Flow on the Ratio Between Oxygen Consumption and Pulmonary Ventilation, Am. J. Physiol. **86**: 274, 1928.

lungs for oxygenation, and with each respiration the suction on the outer surface is increased with a consequent increase in the amount of blood entering the lungs, whereas the expiratory effort drives it out again. . . . We must therefore come to the conclusion that the greatest amount of blood is found in the expanded lung, less in the collapsed lung and least in the compressed lung.

We shall recapitulate this phase of the question with a quotation from Bruns:

The amount of blood in the lung is proportionate to its degree of inflation. The more pronounced is its degree of airlessness the smaller will be the blood volume and velocity of circulating blood. This is true independently of the mechanism of the production of the collapse.

CIRCULATION IN THE PNEUMONIC LUNG

The problem of circulation in the consolidated (pneumonic) lung is still unsolved. There is a characteristic confusion in textbooks and apparent hesitancy on the part of the authors to conciliate these two contradictory facts: the facility with which injections can be made into the vessels and the obvious decrease in the amount of blood that the consolidated lung seems to contain when examined on the autopsy table. There is another cause of confusion; that is, the apparent differences in blood content at different stages of the pneumonic process, as in the stages of engorgement, and red and gray hepatization. "The capillaries of the alveolar walls," according to MacCallum,[120] "are dilated with blood and there exudes into the air cells fluid from the blood together with leukocytes and red corpuscles." Again, he stated that "the capillaries of the alveolar walls are quite patent, as can be shown by injection, but they seem compressed by the mass of exudate and no longer seem distended with blood." There are no accurate descriptions to be found concerning the state of circulation in the transition stages from the so-called stage of engorgement to that of red or gray hepatization; if the ischemia in the affected lung were due to compression of the capillaries by the exudate, we should expect to find such a graded impairment in the circulation, especially if the consolidation were advancing from the lobuli toward the bronchi as many believe. "In spite of what was said about the state of engorgement, it is rare to find anything but an abrupt transition from a consolidated to an unaffected lung substance" (MacCallum [120]). Some idea may thus be had as to the nicety of our knowledge concerning a fundamental question of pathology.

Lundsgaard and van Slyke,[9] in their painstaking work on cyanosis, stated: "We are still uncertain concerning the main factor preventing the reoxygenation of the blood." They considered that cyanosis may be

120. MacCallum, W. G.: A Textbook of Pathology, Philadelphia, W. B. Saunders Company, 1924.

due to insufficient oxygenation of the blood passing aerated lung tissue (factor designated by these authors by *l*) or to a fraction of blood passing consolidated and unaerated lung tissue (factor designated by *a*). The disappearance of cyanosis after the administration of oxygen (Means and Barach,[121] Barach and Woodwell,[122] Stadie [123]), the extensive consolidation found without cyanosis (Stadie [123]), and the bloodless condition of the consolidated lung in gray hepatization, are, according to Lundsgaard and van Slyke,[9] against the latter hypothesis. "It appears that the blood flow through the affected part is either prevented or much diminished, so that it is not likely to approach the necessary fraction, that is the third of the total blood flow ($a = \frac{1}{3}$), required to cause cyanosis."

Judging the physiologic, anatomic and pathologic evidence available, one inclines to the point of view that the circulation in the pneumonic lung is impaired. Thus far two theories have been proposed to explain this impairment. One attributes it to multiple capillary fibrinous thrombi or emboli in the pulmonary vessels and capillaries; the other, to the compression exerted on the capillaries by the exudate contained in the alveoli. We do not believe that either of these two theories is tenable. Another explanation for the impairment of circulation will be developed subsequently. It is one which is suggested by our experimental observations and seems to be more in conformity with the available data on the lung. Ribbert,[11] in 1894, in an addition to an article of Dom Bezzola [124] on the histology of lobar pneumonia, stated that one should not make inferences from the condition of the lung as seen on the autopsy table, and that it might contain much more blood during life than after death; the color of the blood contained in the capillaries might well be masked by the color of the exudate. There is no doubt in his mind that the pneumonic lung is poorer in blood than the normal one. He rejected the theory of capillary obstruction by compression by the intra-alveolar exudate. The existence in the lumina of the capillaries of fibrinous clots and thrombi was sufficient for him to explain the circulatory deficiency. "In sections colored by Weigert's method in conjunction with carmine, numerous fibrinous deposits were found in the smaller and larger vessels. In some places, a kind of fibrin network with fine threads and large loops were seen; in others, there were more com-

121. Means, J. H., and Barach, A. L.: The Symptomatic Treatment of Pneumonia, J. A. M. A. **77**:1217 (Oct. 15) 1921.

122. Barach, A. L., and Woodwell, M. N.: Studies in Oxygen Therapy in Pneumonia and Its Complications, Arch. Int. Med. **28**:394 (Oct.) 1921; Studies in Oxygen Therapy with Determination of the Blood Cases, ibid. **28**:367 (Oct.) 1921.

123. Stadie (footnote 10, second reference).

124. Dom Bezzola: Beiträge zur Histologie der fibrinose Pneumonie, Virchows Arch. f. path. Anat. **136**:345, 1894.

pact formations always connected with the intima of the vessels. Often real thrombotic processes were encountered as ringlike deposits on the intima, and fibrin and white cells narrowing the lumina of the vessels. There may even be thrombi composed of fibrin, white cells and platelets occluding the vessels more or less completely. Seldom was obstruction observed to be so complete as to permit no passage of blood. Of special interest was the occasional observation of complete thrombosis of all the capillaries around an alveolus without signs of infarction."

MacCallum [120] is less affirmative as to the cause of anemia. He agrees, however, with Ribbert [11] that "one may often find capillaries obstructed by a huge cellular mass which proves to be megalokaryocytes from the bone marrow." Pratt [125] noticed thrombosis usually only in the smaller vessels and capillaries, consisting of finely granular material seldom completely occluding the lumina of the vessels. Besides, Pratt reported the presence of emboli composed of giant cells from the bone-marrow. He concluded that both the thrombosis and the compression of the capillaries by exudate are more important factors in the anemia and gray color of the consolidated lung than the substitution of white cells for the red which Aufrecht [126] holds to be the only cause. Aschoff,[127] Lubarsch [128] and Maximow [129] have studied the same giant cells and considered them as causes of embolism in the capillaries and arterioles of the pulmonary arteries. Rindfleisch, on the contrary, considered as the cause of impairment the compression of the capillaries by alveolar exudate. Mallory [130] is still more affirmative:

> As the exudate increases in amount and the fibrin network thickens, the air sacs are greatly distended, the alveolar walls stretched and the capillaries compressed so that they no longer appear engorged. As a result, the redness due to congestion and to some extent to hemorrhage, fades away and the lung passes into the stage known as grey hepatization.

Aschoff [131] attributed the gray color of the consolidated lung to the great number of white cells and to the compression of the capillaries by the exudate.

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125. Pratt, J. H.: The Histology of Acute Lobar Pneumonia, Johns Hopkins Hosp. Rep. **9**:265, 1900.

126. Aufrecht: Die genuine Lungenentzündung und die buhlshe desquamative Pneumonie, Deutsche Ztschr. f. Prakt. Med. **45**:373, 1875; Nothnagels spezielle Pathologie und Therapie, 1899, vol. 14.

127. Aschoff, L.: Ueber Capillaren embolosus von Nesenkernhaftigen Zellen, Arch. f. path. Anat. u. Pharmakol. **134**:11, 1903.

128. Lubarsch, O.: Zur Lehre von der Parenchymzellen Embolie, Fortschr. d. Med. **11**:845, 1893.

129. Maximow, A.: Lehre von der Parenchymzellen-Embolie der Lungenarterie, Arch. f. path. Anat. **151**:**297**, 1898.

130. Mallory, F. B.: Principles of Pathological Histology, Philadelphia, W. B. Saunders Company, 1914, p. 472.

131. Aschoff, L.: Pathologische Anatomie, ed. 6, Jena, G. Fischer, vol. 2, p. 284.

The latter opinion is upheld by Christie, Ehrich and Binger,[132] who, in experimental studies on diathermy in pneumonia, observed an elevation of temperature in the pneumonic lung in the dog. They found in pneumococcus type I and *B. friedlander* experimental pneumonia that in most instances a more rapid rate of heating occurred in the affected than in the normal lobes. This local heating was of the order and magnitude found in a lung of which the branch of the pulmonary artery supplying it had been clamped. The authors injected barium gelatin mixture into the pulmonary arteries (in lungs of a pneumonic dog) and they found that there was an obstruction of the pulmonary artery branch in the area corresponding to the part of the lung which showed gross pathologic changes at autopsy. They do not, however, consider this specimen as definite proof of vascular obstruction, and are rather inclined to believe that there was a faulty technic (personal communication). In man, the results were not so marked as for the dog. They concluded that there is a marked impairment in the circulation in the pneumonic lobes but that this is due to compression of the capillaries by the alveolar exudate.

Gross [13] injected oxychloride of bismuth in gelatin into pneumonic lungs, post mortem. In the healthy lung the vessels are uniformly injected (fig. 5). He concluded in his work that varying degrees of vascular obliteration may occur depending on the stage of the consolidation. In red hepatization there is a moderate impairment of the circulation and although the involved parenchyma of the lung, macroscopically at least, looked as though nonfunctioning, there was still a moderate circulation going on. On the contrary, in gray hepatization there is a complete lack of injection and only large branches, ending abruptly, are injected; the whole area of gray hepatization shows a strikingly anemic condition (fig. 6).

The most complete experimental study on this question was made by Kline and Winternitz.[12] These authors observed that when pneumonia is produced in animals which were previously given injections of vital stain (trypan blue), the involved lung had a uniform blue color. However, when the dye is injected from twenty to sixty-five hours after pneumonia is produced, the normal lung will appear a uniform blue whereas the consolidated areas will not take the dye. These areas present a pale gray color, as do the nonstained specimens. The sharp demarcation of these wedge-shaped infarct-like areas was so striking that these authors investigated the question further. In a

132. Christie, R. V.; Ehrich, W., and Binger, C. A. L.: An Experimental Study of Diathermy: 5. The Elevation of Temperature in the Pneumonic Lung, J. Exper. Med. **37**:741 (May 1) 1928. Binger, Christie and Ehrich (footnote 14, second reference).

case of pneumonia of the right middle and lower lobes in man, three and one-half hours after death, they injected into the pulmonary artery equal parts of 5 per cent berlin blue in 10 per cent gelatin under a pressure of 120 mm. of mercury. After the injection, the pulmonary artery was tied and the lungs placed in a diluted solution of formalde-

Fig. 5.—Normal lung into which bismuth oxychloride gelatin was injected through the pulmonary artery (after Gross).

hyde, U. S. P. (1 : 10) overnight. The following morning a striking picture presented itself. The consolidated area was pale gray, whereas the healthy lung was intensely blue. Four subsequent specimens treated in the same way yielded similar results. The same results were obtained with injections into pneumonic lungs of rabbits after death. Micro-

scopic sections in man and in rabbits showed that little blue solution had penetrated the consolidated area, whereas the vessels of the healthy lung were engorged with the blue solution. Apparently there was an impairment of the circulation in the consolidated lung, at least in the postmortem specimen.

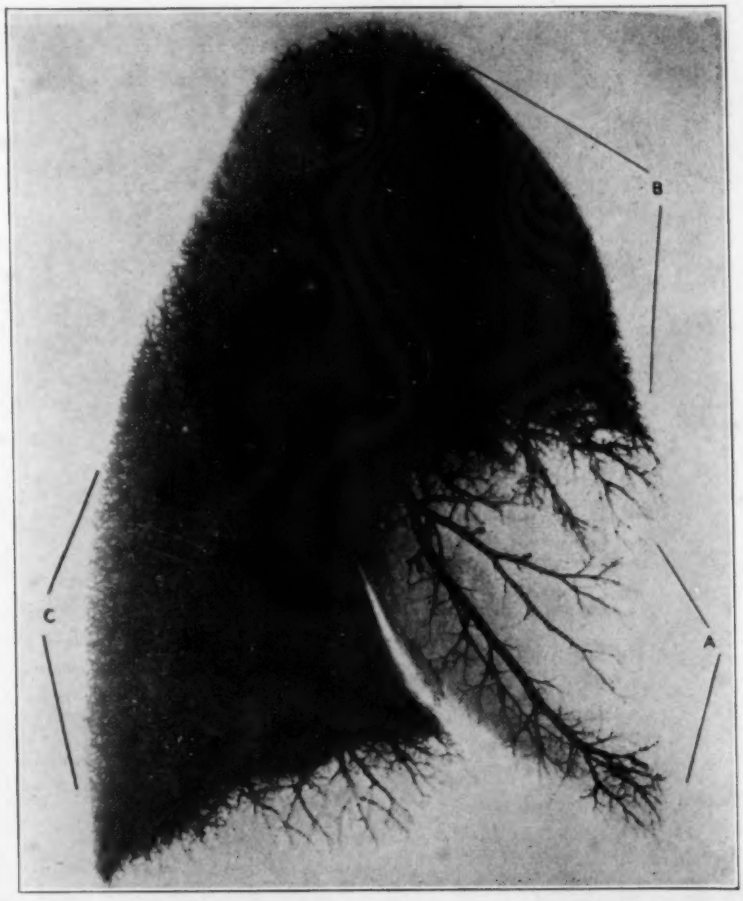

Fig. 6.—Roentgenogram of a lung from a case of lobar pneumonia into which bismuth oxychloride-gelatin was injected. *A*, consolidated area—gray hepatization—the main vessels though constricted are functioning while the finer vasculature has been obliterated. *B*, consolidated area—red hepatization—the main vessels are constricted and the finer vasculature is less dense than normal. *C*, healthy lung tissue except for compensatory congestion. The main and finer vasculature is conspicuously dilated (after Gross, with whose results we are not in agreement).

As a cause of such impairment, the authors considered the following hypotheses: (1) compression of the alveoli by the intra-alveolar

exudate and (2) obstruction of the blood vessels by fibrinous thrombi. Into the rabbit's lung, the left lobe of which was distended with air so that its volume was considerably greater than if it had been the site of lobar pneumonia, they injected the gelatin berlin blue mass into the pulmonary artery under a pressure of 120 mm. of mercury. The result was negative. Macroscopically and microscopically, there was no difference in color between the distended and normal lobes.

In another set of experiments they injected a 10 per cent gelatin solution at body temperature into the left bronchus under a pressure of 120 mm. of mercury. The lungs were then placed in cold water to allow the gelatin mass to solidify, after which a gelatin berlin blue mass was injected through the pulmonary artery. Both macroscopically and microscopically, the distended as well as the deflated areas were colored uniformly blue; there were no differences in penetration of dye in the capillary vessels. In other rabbits, freshly drawn rabbit blood was injected into the bronchus of one lobe to distend the alveoli, and then the same gelatin blue solution was injected into the pulmonary artery. Again negative results were obtained. These experiments indicated that the impaired circulation in the pneumonic lung cannot be due to the pressure of exudate within the alveoli. The only remaining factors to which the pallor and impairment of circulation could be ascribed by Kline and Winternitz [12] were the white cells, the fibrin or both. Aplastic anemia was therefore produced in rabbits by injections of benzene until the white cell count was under 1,000 per cubic centimeter, and then pneumonia was produced. Twenty-four hours later, the animals were killed. All showed a lobar type of consolidation. A berlin blue gelatin mass was injected into the pulmonary artery. No coloration of the consolidated lungs occurred, whereas the normal lungs were deep blue. In microscopic sections, the interesting observation was made that the exudate contained few leukocytes and consisted almost entirely of fibrin. This is an additional proof that the gray coloration cannot be due to the white cells alone; nor can the impairment of the circulation be ascribed to compression by the exudate due to the influx of white cells into the alveoli during the phase of gray consolidation.

In order to determine whether the fibrin was the principal factor in vascular obstruction, Kline and Winternitz produced pneumonia in animals in which fibrin formation was inhibited by the use of a solution containing phosphorus in olive oil and 0.9 per cent chloroform in 30 per cent alcohol. This was given by stomach on two successive days. Twenty-four hours later the clotting time of the blood was found to be greatly delayed, and the resulting clot soft and jelly-like. Pneumonia was produced by intratracheal insufflation of pneumococcus. One animal died seventeen and one-half hours later. At autopsy, it showed "con-

solidation of practically the entire left lobe. . . . Berlin blue gelatine was then injected into the pulmonary artery. On sections the consolidated lung was found to be almost as uniformly blue as the uninvolved lobes. Microscopic sections showed that the exudate contained an abundance of cells but very little fibrin. Furthermore, the vessels in consolidated area, contained a much greater amount of dye than had been observed in any of the other pneumonic lungs."

It is seen from the foregoing observations that most workers are inclined to the view that the circulation in the pneumonic lung is impaired. This fact is perhaps much more important than it has heretofore been considered. As Kline and Winternitz pointed out, it might help one to understand the inefficacy of serum or other therapeutic methods in lobar pneumonia after the third or fourth day of the disease. Moreover, it could explain the crisis or lysis in this disease which so uniformly occurs between the fifth and eleventh day. According to this conception, therapeutic substances introduced by mouth, hypodermically or by vein cannot reach the affected lung (the focus of infection) because of the circulatory impairment. The crisis could be explained on the same basis, for little serum can reach the consolidated area at this stage; so that the proteolytic ferments liberated by the white cells (Opie [133] and Lord [134]) are not neutralized by the antitryptic power of the serum; the digestion of fibrin in the exudate thus proceeds unhampered.

The mechanism of circulatory impairment requires a much more detailed investigation. Kline and Winternitz [12] ruled out the theory of compression of lung vessels by exudate. This opinion of Kline and Winternitz is in accord with our own view; the pneumonic lung being smaller than the healthy one, as we have previously shown,[135] renders the acceptance of the compression theory difficult. Concerning the view of thrombosis and embolism of the capillaries as factors in impairment, we shall simply state that it is not in agreement with our knowledge about pulmonary infarction and the lesions produced by it. There is no apparent reason for the strict localization of this thrombotic or

133. Opie, E. L.: Intracellular Digestion: The Enzymes and Anti-Enzymes, Physiol. Rev. **2**:252 (Oct.) 1922; The Enzymes in Phagocytic Cells of Inflammatory Exudates, J. Exper. Med. **3**:410 (May) 1926.

134. Lord, F. T.: The Relation of Proteolytic Enzymes in the Pneumonic Lung to Hydrogen Ion Concentration: An Explanation of Resolution, J. Exper. Med. **30**:379, 1919; Pneumonia, Harvard Health Talks, 1929, no. 9, Cambridge, Harvard University Press. Lord, F. T., and Nye, R. N.: Studies in Pneumonic Exudate, J. Exper. Med. **34**:201, 1921.

135. Coryllos, P. N., and Birnbaum, G. L.: Lobar Pneumonia Considered as a Pneumococcic Massive Atelectasis of the Lung, Bull. N. Y. Acad. Med. **4**:384, 1928; Lobar Pneumonia, Arch. Surg. **18**:190 (Jan.) 1929; The Size of the Consolidated Lung in Lobar Pneumonia, Am. J. M. Sc. **178**:15 (July) 1929.

embolic process to the small branches and capillaries of the pulmonary artery alone, while the bronchial arteries and peribronchial capillaries, on the other hand, remain unaffected. For reasons developed in an earlier part of this paper, we should expect infarction and trophic disturbances of the parenchyma of the lung if thrombosis of both systems of vessels were present. Finally, we wish to add that the results obtained by injection into the pulmonary artery both by Binger and his collaborators,[136] Gross,[13] etc., of such substances as these authors used, are open to serious objections, especially since postmortem specimens were used.

EXPERIMENTAL DATA

The desideratum in an injecting substance is that (1) it should be nontoxic and injected into the right side of the heart of the living animal; it must produce no alterations in the blood (like coagulation of the albumin); (2) it should be fluid enough to pass through the smallest ramifications of the pulmonary arteries, and (3) have radiopaque properties for its detection in roentgenograms. Thus far the substances used by Gross [13] (oxychloride of bismuth in gelatin) or by Binger and others (powdered barium sulphate in gelatin) or the vital stains of Kline and Winternitz [12] fall short of these requirements.

For these reasons, we used iodized oil 40 per cent. The results were surprising and quite different from those of other investigators. Iodized oil proved to be the ideal substance for this purpose because it can be injected into the jugular vein of the living dog without pressure and in amounts (from 10 to 40 cc.) compatible with survival of the animal for several minutes. Ample time was thus given the right side of the heart to propel the substance through the pulmonary artery to the lungs of its own accord. Roentgenograms showed that there was no obstruction in the vascular tree of the pulmonary artery, a condition which Gross,[13] Binger [137] and co-workers, and Kline and Winternitz [12] believed to exist and figured (figs. 5 and 6). The smallest ramifications of the pulmonary artery were clearly shown in fine detail in the diseased portions of the lung as well as in the healthy lung. From roentgenograms of the lung alone the affected lobes cannot be distinguished from the healthy lungs.

The patency of the pulmonary arterial tree was thus established. However, this gave us no information about the more important question of circulation in the capillaries of the lung. The fact that the finest arborizations of the pulmonary artery were so clearly shown

136. Branch, A.; Brow, C. R., and Binger, C. A. L.: Internat. Assoc. Med. Mus. Bull., 1925, no. 10, p. 48.

137. Binger; Christie and Ehrich (footnote 14, second reference). Branch; Brow and Binger (footnote 136). Christie; Ehrich and Binger (footnote 132).

raised doubt in our minds about the ability of iodized oil to pass through the precapillary arterioles. Roentgenograms of the heart, after the aorta was clamped, showed the right side of the heart still filled with iodized oil, but no trace of it was discernible in the left side (fig. 7). This showed us that iodized oil was not a suitable substance for investigation of the capillary circulation.

For that purpose we used the technic first suggested by Krogh [62] and later used by Binger, Brow and Branch [136] in their study of their

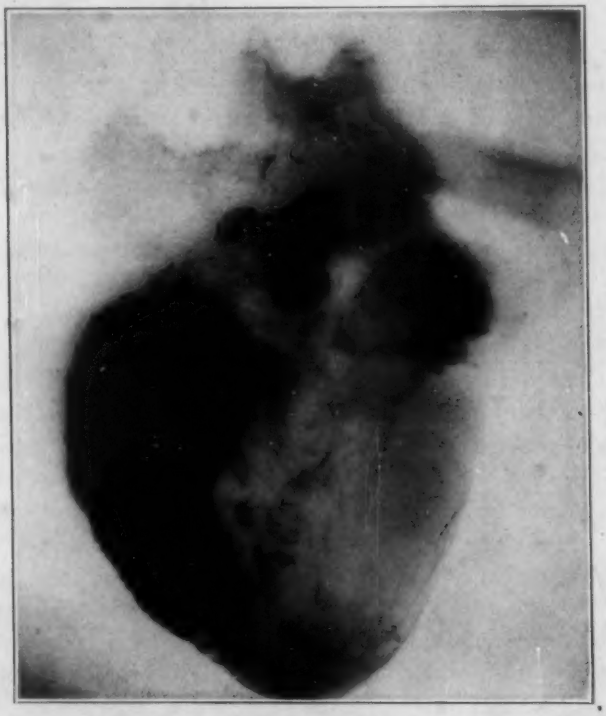

Fig. 7.—Heart after injection of iodized oil into the jugular vein. The right side of the heart is filled with oil, but there are no traces of it in the left side, showing that iodized oil does not pass through the pulmonary capillaries back to the left side of the heart in this short time.

"starch" lungs. A 20 per cent solution of india ink in Ringer's solution is injected through the jugular vein of the living animal after the blood is washed out with a stream of Ringer's solution heated to body temperature. Perfect injection of the capillaries can be obtained. In microscopic sections of the normal lung, the capillaries are black and outline the alveoli clearly. By this method we were able to visualize the changes in alveolar size both in experimental atelectasis and in pneumonia, and the changes in the shape, size and content of the capillaries

incident thereto. The similarity of changes in the circulation revealed for both diseases is really very striking.

For a detailed description of the technic of experimental production of atelectasis and pneumonia, we refer the reader to previous papers.[138]

TECHNIC

Injections of Iodized Oil.—Thirty-four dogs were used, sixteen with atelectasis and eighteen with pneumonia. Atelectasis was produced from twenty-four to forty-eight hours previously by our method. Pneumonia was induced from six to thirty-six hours previously by the intrabronchial insufflation of pneumococcus type 1, by our technic.

The animals were anesthetized with a 10 per cent solution of iso-amyl-ethyl barbituric acid, given intraperitoneally in a dosage of 55 mg. per kilogram of body weight. The right external jugular vein was prepared, a cannula introduced, the distal part clamped with a serrefine and the animal placed on our x-ray stand. The iodized oil was warmed to body temperature and injected into the vein in amounts of 10 cc. This quantity was injected in one minute; very little pressure on the piston of the syringe was necessary. Serial roentgenograms were taken at intervals of from one to five minutes. The animals showed a variable ability to withstand the injections of iodized oil; they generally survived the injection of 10 cc. for from ten to forty minutes, or even sixty minutes. The atelectatic animals were far more resistant than the more toxic pneumonic dogs.

Forty cubic centimeters of iodized oil is uniformly fatal, the animals surviving only from two to five minutes. Smaller doses of 5 cc. may be withstood for twenty-four hours and doses of 1 or 2 cc. do not appreciably affect the animal. This point is now under investigation.

Injections of India Ink.—Atelectatic and pneumonic dogs were used; the usual anesthesia was given. The external jugular vein was dissected free and sectioned between two serrefines. Cannulas were introduced into both the distal and the proximal cut ends of the vein. Injections were made with the simple aid of gravity; that is, the levels of the injecting fluids were 50 cm. above the level of the heart. Ringer's solution and a 20 per cent solution of india ink in Ringer's solution, 1,500 cc. of each, at body temperature, were placed in 4 liter bottles which were held bottom side up on a special rack. These bottles were so connected by rubber tubing to a glass "Y" tube that one or the other solution could be let into the vein. When it was time to begin the injections, the blood was allowed to flow out of the upper cut end of the jugular vein, while at the same time Ringer's solution was introduced into the proximal cut end. In this way the blood was being continuously washed out of the circulatory system, and when the return flow from the cephalad cut end of the jugular vein was of a thin, watery consistency, the injection of Ringer's solution was stopped and immediately replaced with an injection of india ink. Generally, within from ten to fourteen seconds, the india ink would appear at the upper (cephalad) cut end of the jugular vein. It is well not to push the washing out with Ringer's solution too far before shifting to the india ink for the animal rarely survives for more than two or three minutes after the injection of ink is started. Usually from 1,000 to 1,500 cc. of Ringer's solution is sufficient for the technic described.

After the death of the animal, the trachea was clamped to avoid collapse of the lung. When the chest was opened, the lungs were found to be uniformly

138. Corylloss and Birnbaum (footnotes 109 and 135).

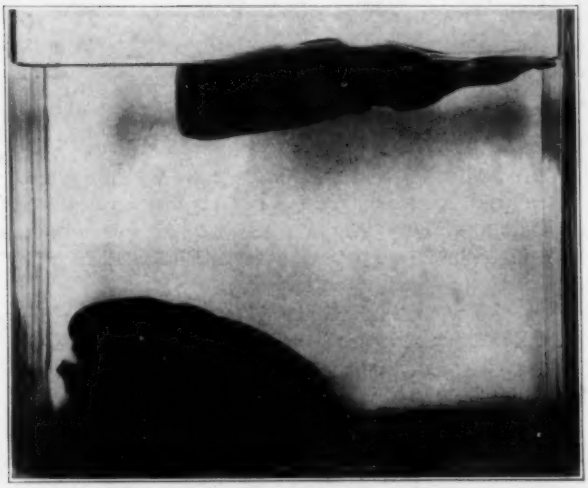

Fig. 8.—Hydrostatic test of degree of airlessness. The normal lung floats; the completely apneumatic lung sinks readily in water.

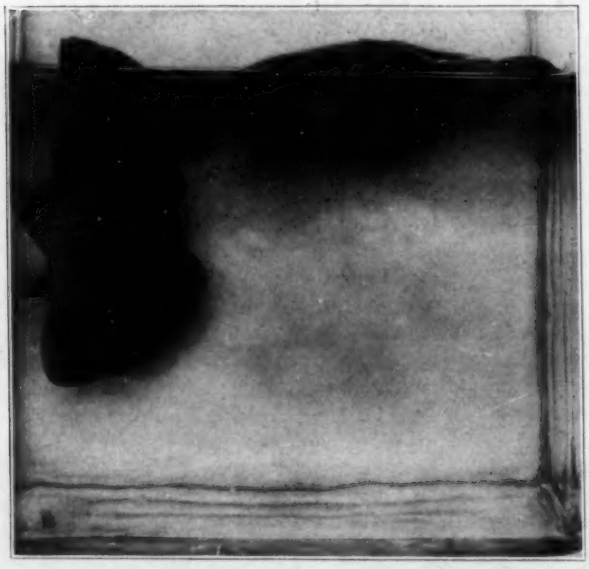

Fig. 9.—Hydrostatic test of degree of airlessness. The left lung is aerated and floats. The right lung shows varying degrees of airlessness. Small specimens from the upper part floated; those from the midportion submerged, and those from the lower part slowly sank in water.

black. In some cases there were patches of less deeply colored tissue, but these were met with in healthy portions of the lung as well as in the affected lung. They were due, we believe, possibly to incomplete washing out of the blood. After the death of the animal and before the lungs were removed from the chest, all main vessels to and from the heart and to and from the lungs were carefully ligated. Small specimens about 1 cc. in size were cut from different portions of the lung to test their degree of atelectasis when allowed to fall into a container of water. We distinguished four groups: floating, submerging, slowly sinking and readily sinking. We have always found the degree of atelectasis as shown by microscopic section proportionate to the readiness with which the specimen of lung sinks to the bottom in a container with water (figs. 8 and 9).

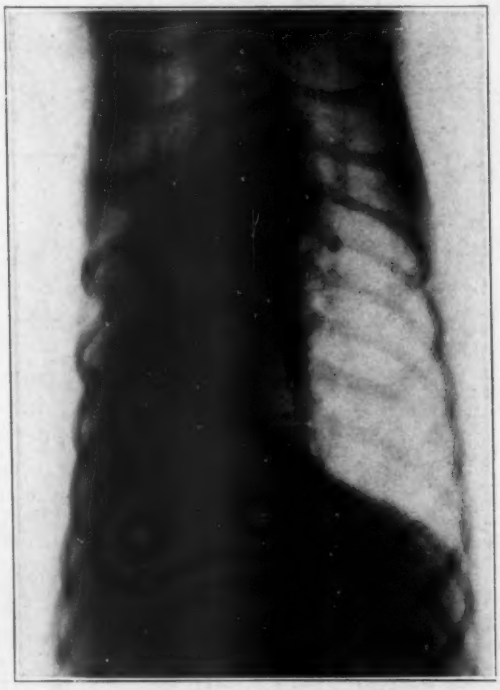

Fig. 10 (dog C 52).—Roentgenogram of complete atelectasis of the right lower lobe twenty-four hours after obstruction of the right lower lobe with special balloon. Displacement of the heart to the right and elevation of the right side of the diaphragm are plainly seen. The balloon is outlined.

Specimens were fixed in a diluted solution of formaldehyde, U. S. P. (1:10) for microscopic section. Both stained and unstained sections were prepared.

PROTOCOLS

We shall give only seven protocols, each representative of its group: five for injections of iodized oil (atelectasis of the right and left lungs, pneumonia of the right and left lungs and pleurilobar pnuemonia), and two for injections of india ink (one in atelectasis and one in pneumonia).

INJECTIONS OF IODIZED OIL

I. Atelectasis of the Right Lung: Dog C 52 was used in this experiment.

March 20, 1928, 10:00 a. m.: The right lower lobe was blocked with our balloon.

March 21, 10:00 a. m.: Roentgen examination showed atelectasis of the right lower lobe (fig. 10). Displacement of the heart and trachea to the right and elevation of the right side of the diaphragm were plainly seen. Iso-amyl-ethyl barbituric acid anesthesia was used.

11:00 a. m.: Ten cubic centimeters of warm iodized oil was injected over a period of one minute into the jugular vein. Roentgenograms were taken every three minutes. After the injections, the dog developed dyspnea and shallow

Fig. 11 (dog C 52).—Roentgenogram taken just before death of the animal showing the pulmonary artery injected with iodized oil; the branch to the involved right lower lobe is markedly dilated.

breathing which lasted for about two minutes; 10 cc. more of iodized oil was injected. The animal again became dyspneic, and forty-five minutes later the heart action became weak; the heart stopped shortly thereafter. Figure 11, taken before the death of the animal, shows both pulmonary arteries injected, but the branch corresponding to the involved right lower lobe is dilated.

At postmortem examination, the trachea was clamped, the lungs extracted and the large vessels of the heart and of the hilum of the lung clamped and ligated. In the photograph of the specimen (fig. 12), a complete apneumatosis of the right lower and subcardiac lobes is clearly visible. In the roentgenogram of the lung (fig. 13), the obstructing balloon is visible because of the sodium iodide solution

with which it is filled. The pulmonary arterial tree is uniformly injected with iodized oil. No differences can be made out between the atelectatic right lobe and subcardiac lobes and the other (normal) lobes. It is to be noted that the smallest arterioles are so clearly outlined that it seems highly improbable that the iodized oil could have penetrated the capillaries; for if the capillaries were filled we should expect a less clearcut and rather blurred roentgenogram.

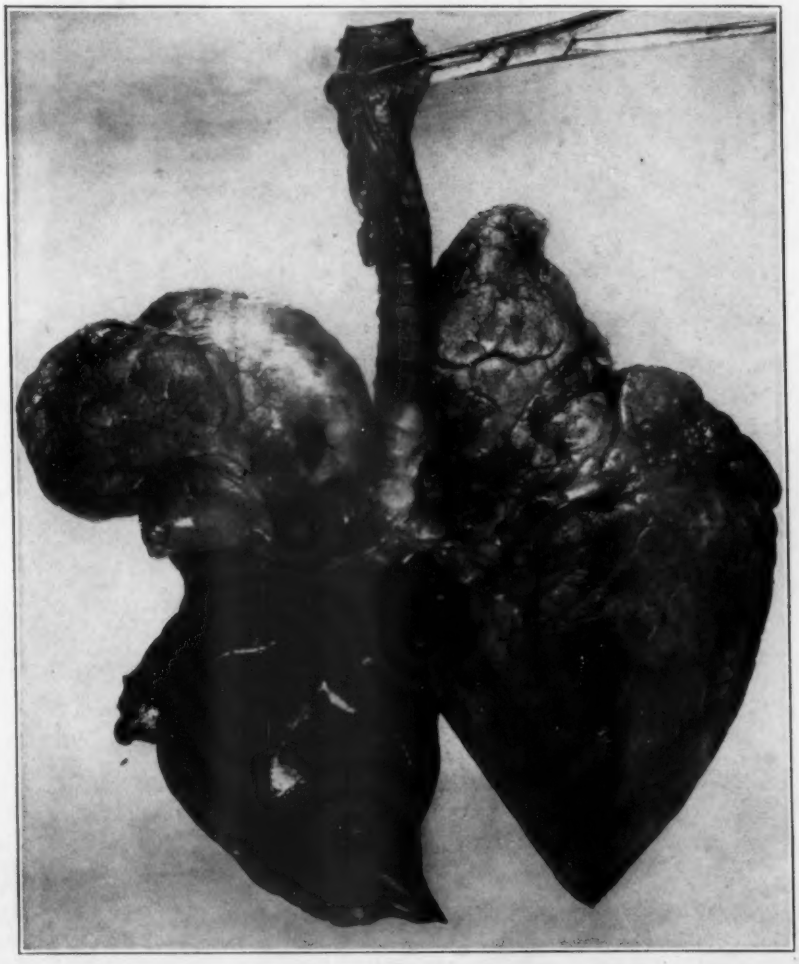

Fig. 12 (dog C 52).—Postmortem specimen of the lung; the trachea was clamped before the chest was opened. The right lower and subcardiac lobes are completely atelectatic.

II. Atelectasis of the Left Lung: Dog C 51 was used in this experiment. The chest was opened, and intratracheal insufflation was employed. The experiment is particularly interesting because it shows the extraordinary resistance of the animal to a marked degree of obstruction of the pulmonary artery, and because the successive injections of iodized oil were followed by serial roentgenograms.

March 19, 1928: Iso-amyl-ethyl barbituric acid anesthesia was given. The left lower lobe was obstructed with our balloon.

March 20: A well developed atelectasis of the left lobe was noted; the heart shifted and the left lower lobe was hazy (fig. 14).

11:30 a. m.: Intraperitoneal anesthesia was given.

12:00 a. m.: The tube for intratracheal insufflation was introduced. An incision of the skin and of the soft parts was made from the manubrium to the mid-abdomen; hemostasis was made. The xyphoid process was dissected free, and the

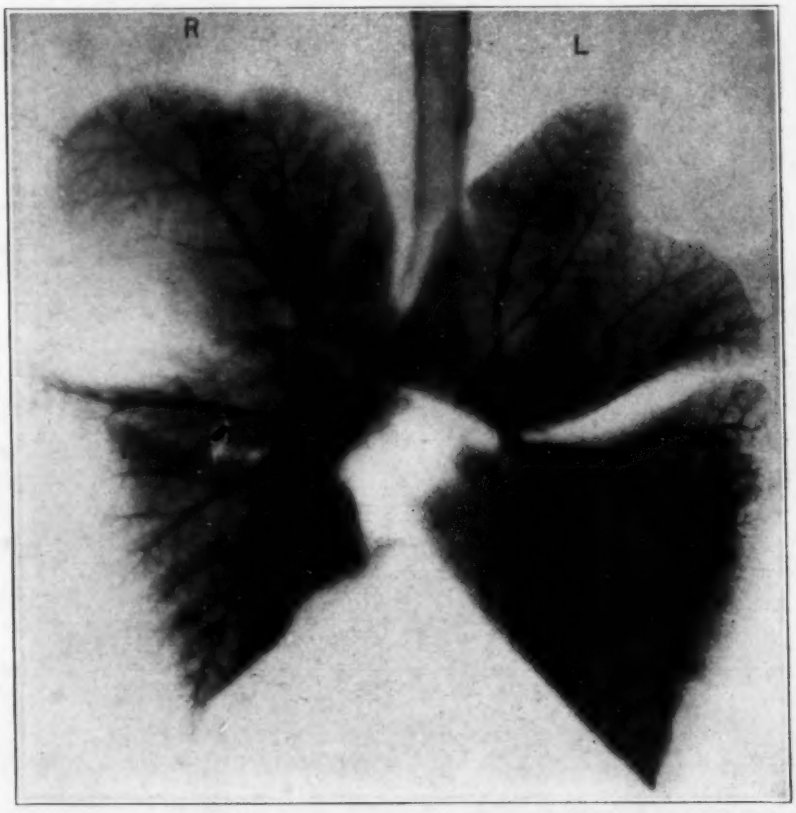

Fig. 13 (dog C 52).—Roentgenogram of the lung showing the balloon obstructing the right lower and accessory lobes. The pulmonary arterial tree is uniformly injected with iodized oil. No differences can be made out between the atelectatic and the other (normal) lobes.

finger passed behind the sternum. Midsection of the sternum was performed. There was slight bone hemorrhage, and the left mammary vessels were ligated. A strong self-retaining retractor was used to separate the edges of the incision widely and so give a satisfactory view of the thoracic cavity. Intratracheal insufflation was established with an air pressure of 12 mm. of mercury. The heart beat was strong and regular. The left lower lobe was atelectatic, bluish black and did not expand with insufflation. The left upper lobe was of normal color and distended. The right lung was normal and distended. The subcardiac lobe

was visible under the heart and displaced toward the left side (represented by the clear triangle between the heart and the diaphragm in the roentgenogram).

1:00 p. m.: The animal was transported to the x-ray table. A cannula was introduced into the right jugular vein and 20 cc. of warm iodized oil was injected in one minute. A roentgenogram taken one minute (fig. 15) after the injection shows that the oil has penetrated the branch of the pulmonary artery to the atelectatic left lower lobe and that this branch is greater in diameter than that to the right lower lobe. (Compare this figure to figure 11, where the right lower branch is larger.)

Five minutes after injection, all branches of the pulmonary artery were seen to be injected and visible; the left lower branch was again seen to be dilated.

Fig. 14 (dog C 51).—Well developed atelectasis of the left lower lobe; the heart is drawn to the left and the left lower lobe is hazy.

1:07 p. m.: Ten cubic centimeters more of oil was injected. The dog was dyspneic, and the heart slowed down but was beating regularly.

1:40 p. m.: The heart action was weak and slow. After massage and intracardiac injection of epinephrine, it again became more rapid. Ten cubic centimeters more of oil was injected.

1:45 p. m.: The heart was beating even more slowly and finally stopped.

At postmortem examination, a clearcut apneumatosis of the left lower lobe only was seen (fig. 16). A roentgenogram of the lung (fig. 17) shows a perfect distribution of iodized oil in all branches of the pulmonary artery. No differences are apparent between the vessels in the affected and healthy lobes. The difference in diameters of the right and left pulmonary artery which shows up clearly in

the living animal is no longer apparent. In the same roentgenogram, the kidney of the animal shows that no iodized oil had penetrated this viscus.

III. Pneumonia of the Right Middle and Lower Lobes: Dog B 57 was used in this experiment.

March 30, 1928, 4:00 p. m.: Intraperitoneal anesthesia was given. Twenty cubic centimeters of a twenty-three hour culture in broth of pneumococcus type I was centrifugated, and the sediment suspended in 1 cc. of broth. This concentrated culture was insufflated into the right common bronchus through the bronchoscope.

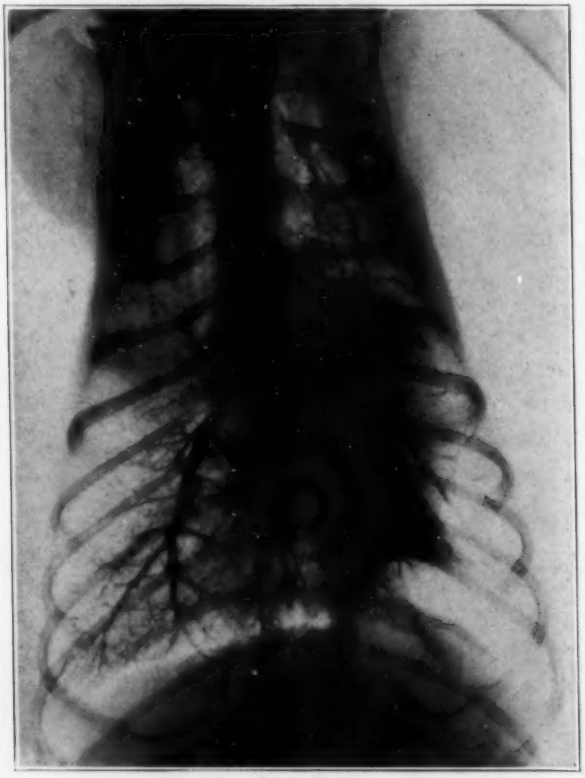

Fig. 15 (dog C 51).—Roentgenogram taken one minute after the injection of 20 cc. of iodized oil. Oil has penetrated the branch of the left pulmonary artery to the left lower lobe, and this branch (faintly shown in this particular figure) is greater in diameter than that to the right lower (normal) lobe. Compare with figure 11. The tracheal tube is seen in place.

March 31: The animal appeared very sick and toxic. The temperature was 103 F., pulse rate 90 and respirations 90. The right side was dull to percussion; there were diminished breathing and a few râles. The heart was markedly displaced to the right. In the roentgenogram (fig. 18) typical pneumonia of the right lower lobe is seen.

12:48 p. m.: Fifteen cubic centimeters of iodized oil was injected into the right jugular vein.

12:52 p. m.: Respiration slowed down after initial acceleration, and the heart stopped beating.

At postmortem examination, the chest was opened without previously clamping of the trachea. A greenish turbid fluid was found in both pleural cavities. A smear showed myriads of diplococci. The right, middle and lower lobes were of a dark reddish blue, airless and sank in water (fig. 8). A photograph of the specimen (posterior view) shows the involved lobes larger than the healthy ones because the trachea had not been clamped previous to opening the chest (fig. 19). A roentgenogram of the lung (fig. 20) shows no impairment in the circulation. It is impossible by this means to distinguish the healthy from the involved lobes.

IV. Pleurilobar Pneumonia: Dog B 56 was used in this experiment. Pneumonia was induced in the left lower and the right, middle and lower lobes. The process

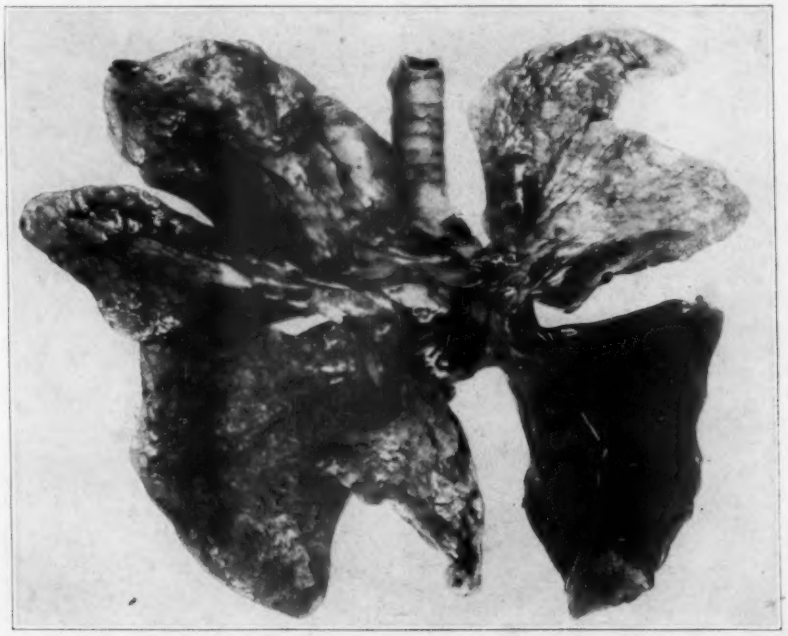

Fig. 16 (dog C 51).—Postmortem specimen showing complete atelectasis of the left lower lobe.

in the left lower lobe was probably seven days old or less and the process in the right lobe six days old or less.

March 27, 1928, 10:00 a. m.: Intraperitoneal anesthesia was given. Twelve cubic centimeters of twenty-hour old broth culture of pneumococcus type I was centrifugated, and the sediment taken up in 1 cc. of broth and insufflated into the left main bronchus through the bronchoscope.

March 28: The animal was not very sick.

March 29: The animal was rather sick. A roentgenogram showed haziness of the base of the left lung, shifting of the heart to the left without elevation of the diaphragm and a haziness of the base of the right lung.

April 5: The animal was very sick. The temperature was 100 F., pulse rate 166 and respirations 140. There was dulness over the right side of the chest

Fig. 17 (dog C 51).—Postmortem roentgenogram of the lung showing a perfect distribution of the oil in all branches of the pulmonry artery. No differences are apparent between the affected and the healthy lobes. The lower figure shows no iodized oil in the kidney of this animal.

and the base of the left lung. A roentgenogram (fig. 21) shows the heart now shifted to the right and the whole right side and the lower left side opaque.

Intraperitoneal anesthesia was given. Twenty cubic centimeters of iodized oil was injected into the right jugular vein. The animal died within two minutes; that is, the respiration stopped after a minute, and the heart stopped beating after two minutes. In a roentgenogram (fig. 22) taken just before the heart stopped, the branch of the pulmonary artery going to the more involved lobe is again larger (right lower larger than the left).

At postmortem examination, the aforementioned lobes were found to be consolidated and rather in the stage of gray hepatization (fig. 23). A roentgeno-

Fig. 18 (dog C 57).—Roentgenogram taken twenty-four hours after insufflation of concentrated culture of pneumococcus type I into the right main bronchus. A typical pneumonia of the right lower and middle lobe is seen; the heart is displaced to the right and the right side of the diaphragm is elevated.

gram of the lung (fig. 24) shows all the lobes well injected. No differences can be made out.

V. Pneumonia of the Right Lower Lobe: Dog 76 was used in this experiment. A roentgenogram was made of the heart. The same procedure was employed as for dog 56.

June 2, 1928, 1:15 p. m.: Thirty cubic centimeters of iodized oil was injected into the right jugular vein. Shallow and rapid breathing with cyanosis ensued.

1:18 p. m.: The shallow breathing stopped. The dog breathed deeply, and the heart beat was strong.

1:22 p. m.: There were deep agonal respirations, with the heart beating regularly at a rate of 100 per minute.

1:23 p. m.: The respiration stopped; the heart was still beating. After rhythmic traction on the tongue, respiration again started, deep at first for a

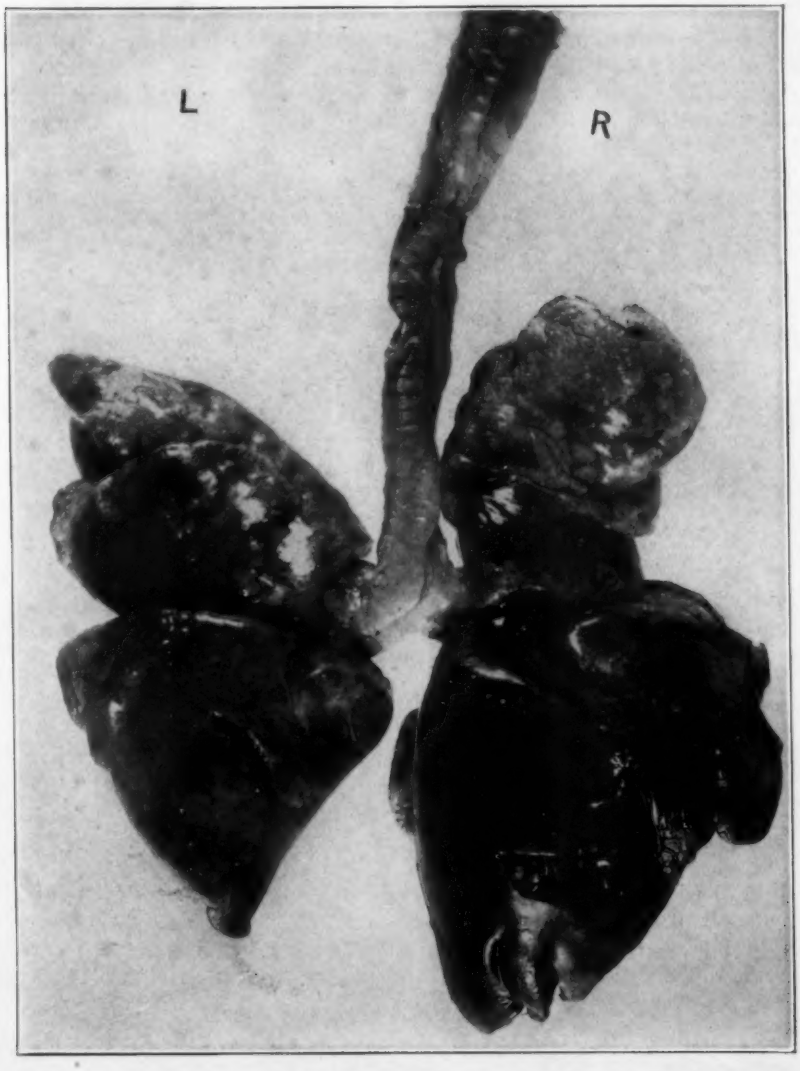

Fig. 19 (dog C 57).—Posterior view of lungs showing pneumonia of the right middle and lower lobes. The trachea is not clamped.

few respirations and then an alternating type with one deep and one shallow respiration.

1:27 p. m.: Respiration stopped.

1:28 p. m.: The heart stopped beating. The chest was opened, and the aorta clamped.

The roentgenograms of the lungs are not given here as they are simliar to those already shown. The interesting feature in this experiment is that a roentgenogram of the heart (fig. 7) shows clearly that the right side is filled with iodized oil whereas the left side contains no trace of it. This experiment gave us the explanation of the peculiar phenomenon that the branches of the pulmonary artery were so well injected down to their finest ramifications; although relatively large amounts of oil were injected, the vessels appear clearcut and the lungs are not

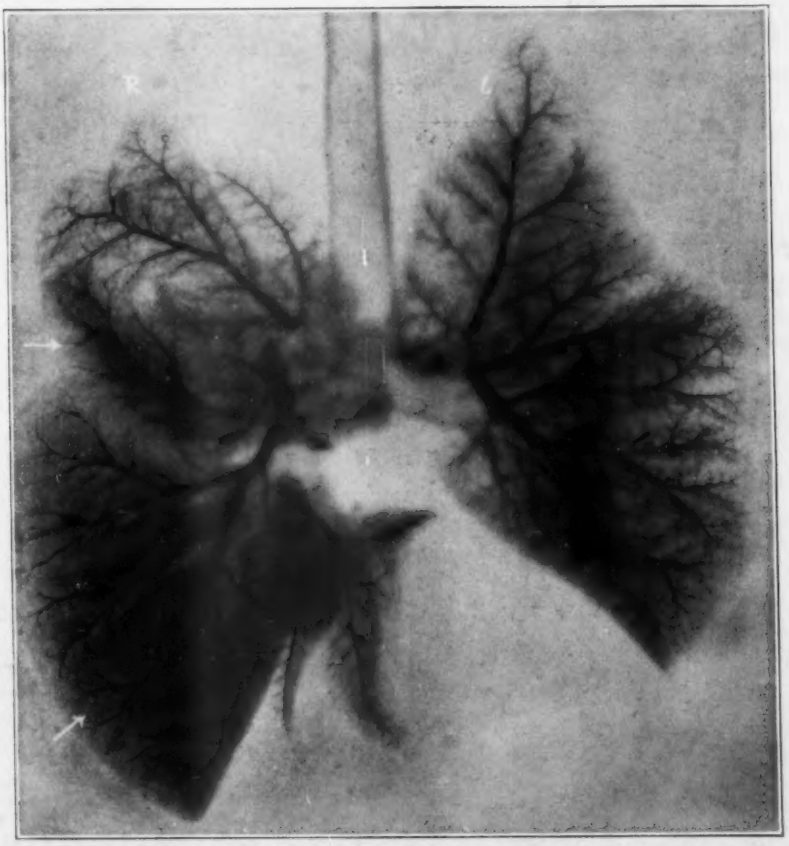

Fig. 20 (dog C 57).—Roentgenogram of the lungs extracted from the chest. The pneumonic right middle and lower lobes (indicated by arrows) are as well injected with iodized oil as the healthy lobes; it is impossible by this means to distinguish them.

diffusely opaque—an opacity which we should expect if the capillaries were injected with oil. We therefore suspected that iodized oil could pass through the precapillary arterioles, but could not penetrate the capillaries; the roentgenogram of the heart, of course, confirms this suspicion.

INJECTIONS OF INDIA INK

Only two cases will be shown here—one of atelectasis and one of lobar pneumonia, the other injections of this series being similar.

VI. Atelectasis of the Right Lung: Dog B 83 was used in this experiment.

June 19, 1928: Intraperitoneal anesthesia was given. In order to produce a rapid atelectasis, the lung was insufflated with a stream of air saturated with ether (Connell insufflating apparatus) through the bronchoscope, and the right lower bronchus was obstructed with our balloon. Ten minutes later a partial atelectasis was apparent, and in one hour the atelectasis seemed complete.

Twenty-four hours later the right jugular vein was exposed and sectioned. A cannula was introduced into the distal end and one into the proximal end, as described under technic.

11:55 a. m.: The introduction of 1,000 cc. of Ringer's solution was started; the return flow of blood was light red. The heart action was rather weak, and 1 cc. of epinephrine was injected into the tube supplying Ringer's solution.

Fig. 21 (dog B 56).—Roentgenogram of the chest, showing pneumonia of the whole right lung, except the accessory lobe, and left lower lobe. Displacement of the heart to the right is less marked because of involvement of the left lower lobe as well.

12:00 a. m.: Ringer's solution was stopped and the injection of india ink solution started. Twelve seconds later, the return flow from the upper end of the jugular vein was completely black.

12:02 a. m.: The heart stopped beating.

The chest was opened. Both lungs were entirely black (fig. 25). The right middle and lower lobes and the subcardiac lobe were completely apneumatotic and sank readily in water (arrows in fig. 25). The right upper and left lobes were healthy and aerated. Specimens were cut from the different lobes and

tested in water. Four varieties were distinguished: *a*, floating; *b*, submerging; *c*, slowly sinking, and *d*, rapidly sinking. Sections were taken from each lobe. In cases of experimental atelectasis we find portions of the affected lobe with complete apneumatosis and others in which the absorption of air is less complete. In other words, the results are similar to those in experimental or human pneumonia in which three stages of consolidation are distinguished: the so-called stage of engorgement, and red and gray hepatization; in the latter, areas of beginning resolution may also be seen.

Figure 26 is a photomicrograph of a section of healthy lung from this animal. Into the capillaries was injected india ink, so that the alveoli are clearly outlined

Fig. 22 (dog B 56).—Roentgenogram of the chest before the heart stopped shows the branch of the pulmonary artery to the more involved side (right middle and lower lobes) to be larger in diameter than the left.

by them. Notice the size of the alveoli for comparison with the following photomicrographs which have been made under the same magnification.

Figure 27 shows incomplete apneumatosis. Alveoli with air are still visible, although the majority of them are shrunken and airless. The capillaries are tortuous, having followed the alveoli in the process of shrinkage. At first sight the circulation does not seem impaired, although the capillaries are somewhat decreased in diameter as shown by careful comparison with the capillaries in the previous photomicrograph. This is particularly well demonstrated when one

takes into consideration the fact that in a given area, say 1 square inch, the present photomicrograph shows twice as many capillaries, since 1 square inch of the present figure contains many more (shrunken) alveoli. Even if one considers that the lung in this state has more blood content per unit volume, nevertheless the blood content per alveolar sac is less and therefore the content for the whole lung is less than for a healthy lung.

Figure 28 shows a more advanced stage of atelectasis. Few alveoli still contain air; exudate is present. The capillaries are irregular and the blood content of the lung is certainly decreased.

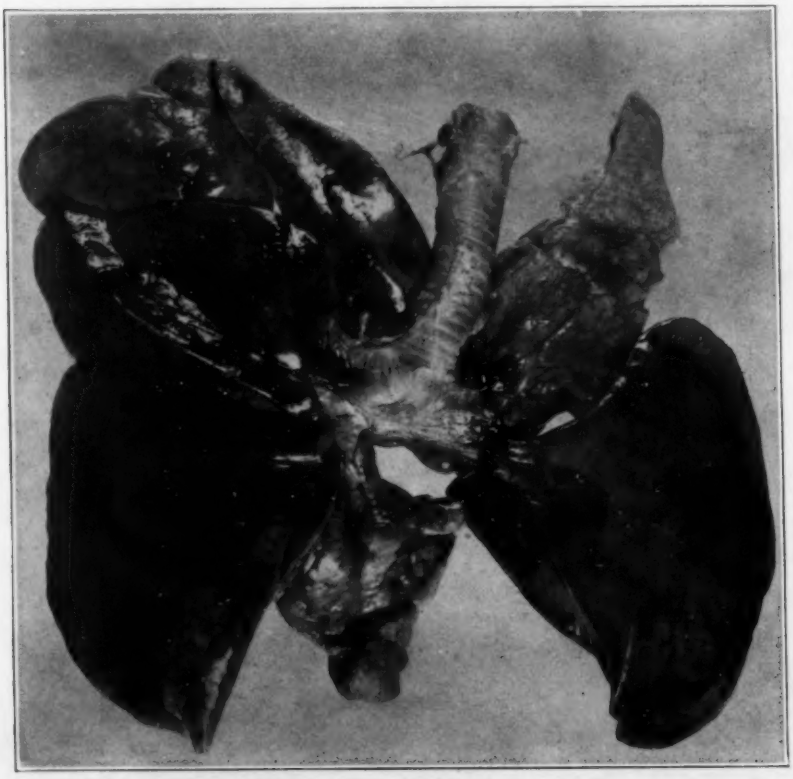

Fig. 23 (dog B 56).—Pneumonia in all the right lobes except the accessory; stage of early gray hepatization.

Figure 29 shows the circulation still more impaired.

An important fact is the simultaneous appearance, with the impairment of circulation, of dilated blood vessels the sizes of which increase in proportion to the circulatory impairment. We believe that these vessels do not represent dilated capillaries, as previously described by Bergamini and Shepherd, Santee, etc., but precapillary arterioles of the pulmonary artery which are dilated because of the resistance met with in the collapsed capillaries. This fact will explain the dilatation in the branches of the pulmonary artery corresponding to the affected lobe so clearly shown in the roentgenograms of the living animal with injections

of iodized oil (figs. 11, 15 and 22). It is of great interest to note in the following experiment that almost exactly the same phenomena were reproduced in cases of pneumonia.

VII. Lobar Pneumonia: Dog B 82 was used in this experiment.

June 13, 1928: Intraperitoneal anesthesia was given. Fourteen cubic centimeters of a twenty-hour old broth culture of pneumococcus type I was centrifugated, the sediment taken up in 1 cc. of broth and insufflated into the left main bronchus with the bronchoscope.

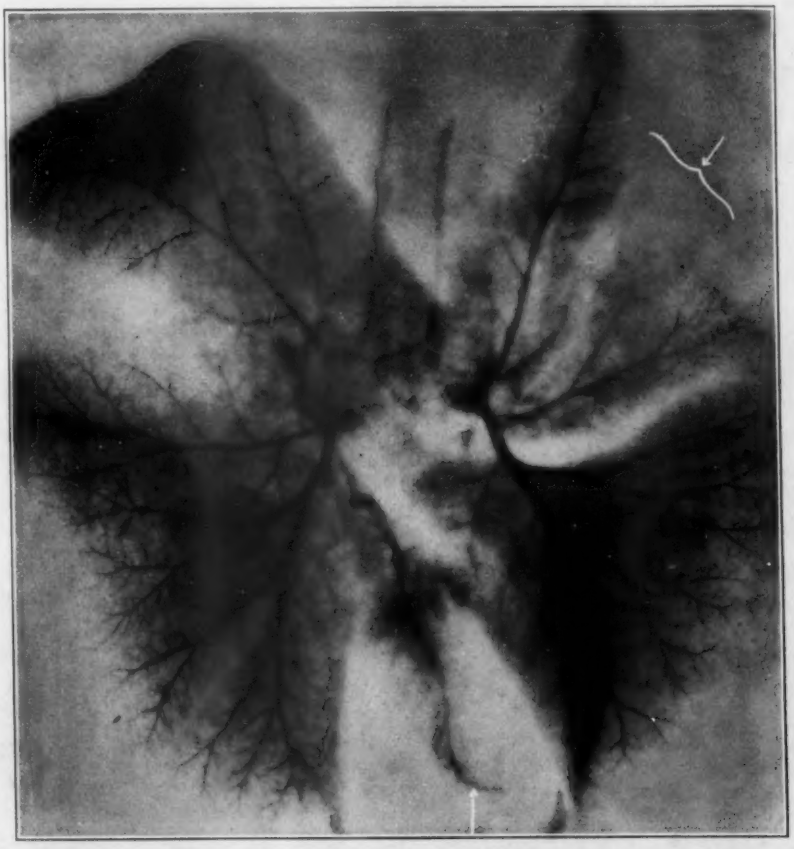

Fig. 24 (dog B 56)—Roentgenogram of lungs extracted from the chest after intrajugular injection of iodized oil. The involved lobes cannot be distinguished from normal lobes. Arrows indicate the healthy lobes.

June 14: The animal was very sick. Breathing was rapid and shallow. The roentgenogram (fig. 30) shows pneumonia in the left lung with complete shifting of the heart to the left and elevation of the left side of the diaphragm. The clear space between the heart and diaphragm is due to the encroachment of the subcardiac lobe on the left side of the chest.

11:50 a. m.: The jugular vein was exposed, sectioned and prepared as described under technic.

12:50 p. m.: Injection of Ringer's solution was started. Over a period of five minutes, 800 cc. was introduced; the return flow was about from 900 to 1,000 cc.

12:55 p. m.: The heart weakened. One cubic centimeter of epinephrine was introduced into the rubber tube going to the jugular vein cannula. The heart rapidly resumed its normal beat, but respiration became shallow and rapid. The outflow of blood from the peripheral cannula was still red but much lighter than at the beginning of the experiment. At this time about 1,000 cc. of Ringer's solution had been introduced. The Ringer's solution was now stopped, and the injection of india ink started and continued for one minute. Twelve seconds after

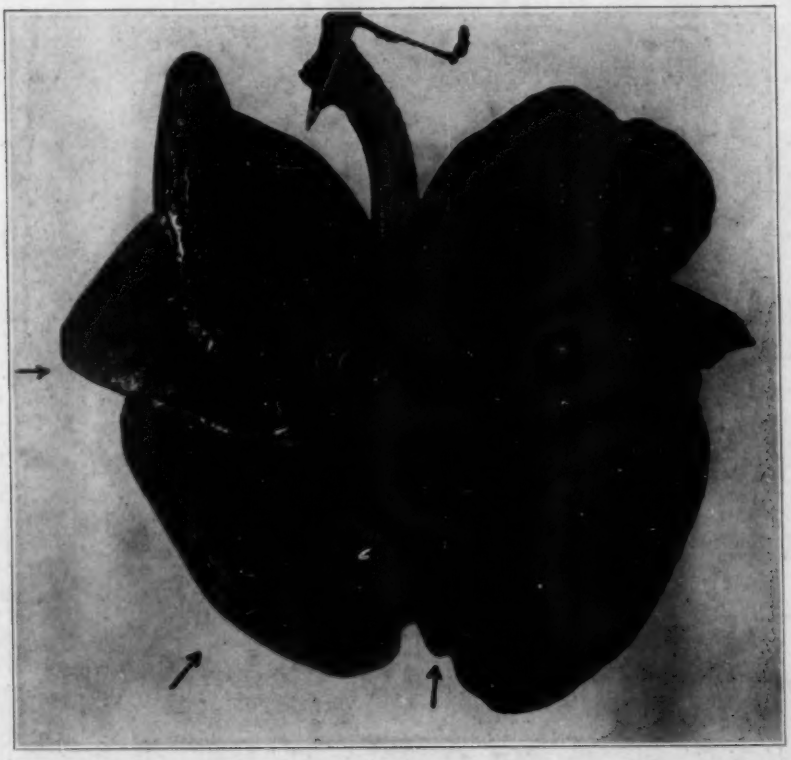

Fig. 25 (dog B 83).—Right atelectasis. Injection of india ink into the jugular vein. The arrows point to atelectatic lobes. All lobes are uniformly black.

the beginning of this injection, the return flow from the upper end of the jugular vein was completely black. Within one minute after the beginning of the injection, the heart stopped beating. The chest was opened and the large vessels of the base ligated. A photograph of the lung (fig. 31) shows it completely black; no differences in color are visible between the affected (left upper and lower) and healthy lobes (right). Specimens were taken and classified according to their behavior in a container with water as in the previous cases. Sections were made of these specimens and photomicrographs taken, the same magnification being used for all of them.

Figure 32 shows a section of a portion of the upper right lobe (normal). The large alveoli are outlined by the capillaries which are well injected with india ink. No dilated vessels are visible.

Figure 33 corresponds to the period of engorgement. This photomicrograph was made from a specimen which submerged but did not sink in water; the alveoli are shrunken but a great number of them are still air-containing. The diameter of the capillaries is decreased as compared with the previous figure. A few dilated vessels appear and these obviously cannot be capillaries because of

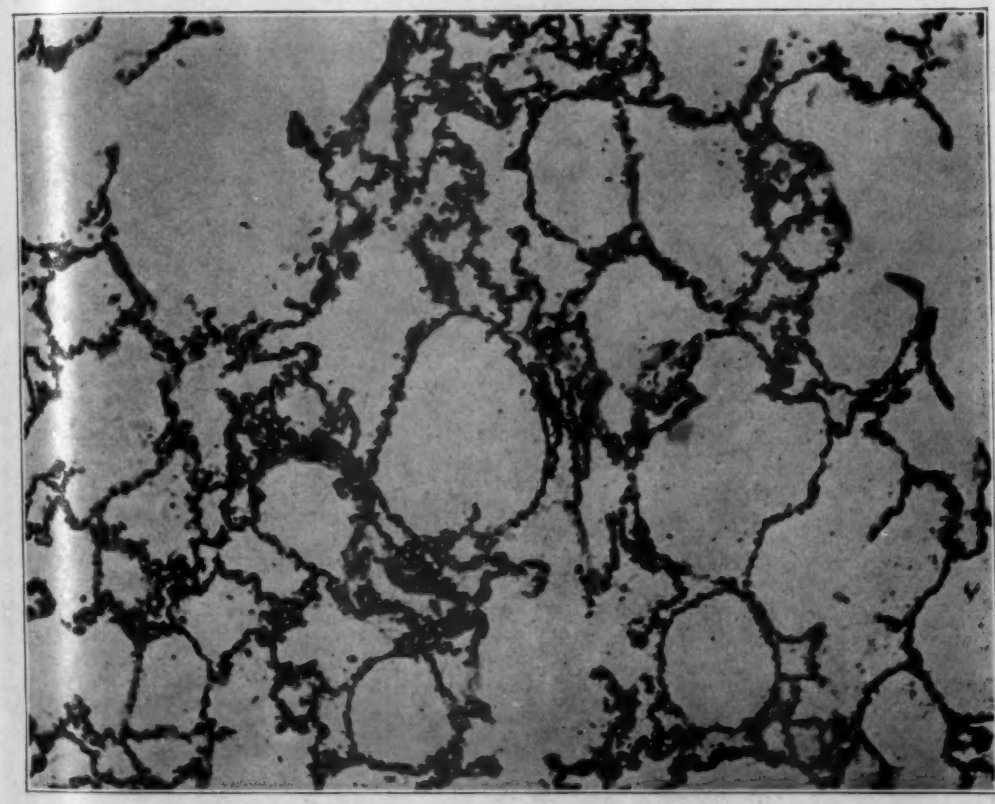

Fig. 26 (dog B 83).—Injection of india ink. Section of healthy lung. The capillaries are injected black with india ink so that the alveoli are clearly outlined by them. Notice the size of the alveoli for comparison with the following photomicrographs, all of which have been made under the same magnification.

their size; in our opinion they represent terminal branches of the pulmonary artery.

Figure 34 represents a more advanced period with exudate in alveoli. The capillary circulation is still more impaired. Cross-sections and longitudinal sections of dilated pulmonary arterioles are more clearly visible in this figure.

Figure 35 shows red hepatization (stained preparation) and complete airlessness of the alveoli. The capillaries are more irregular, and there are large areas

apparently without any capillaries. Sections of dilated arterioles are clearly visible.

Figure 36 shows gray hepatization. The circulation is more impaired, and the capillaries broken up. Sections of dilated arterioles are seen.

DISCUSSION

Before we comment on our observations, it will be necessary to see how the theory we propose agrees with the known facts on disturbances of gaseous exchanges in the lung in cases of inflammatory diseases of

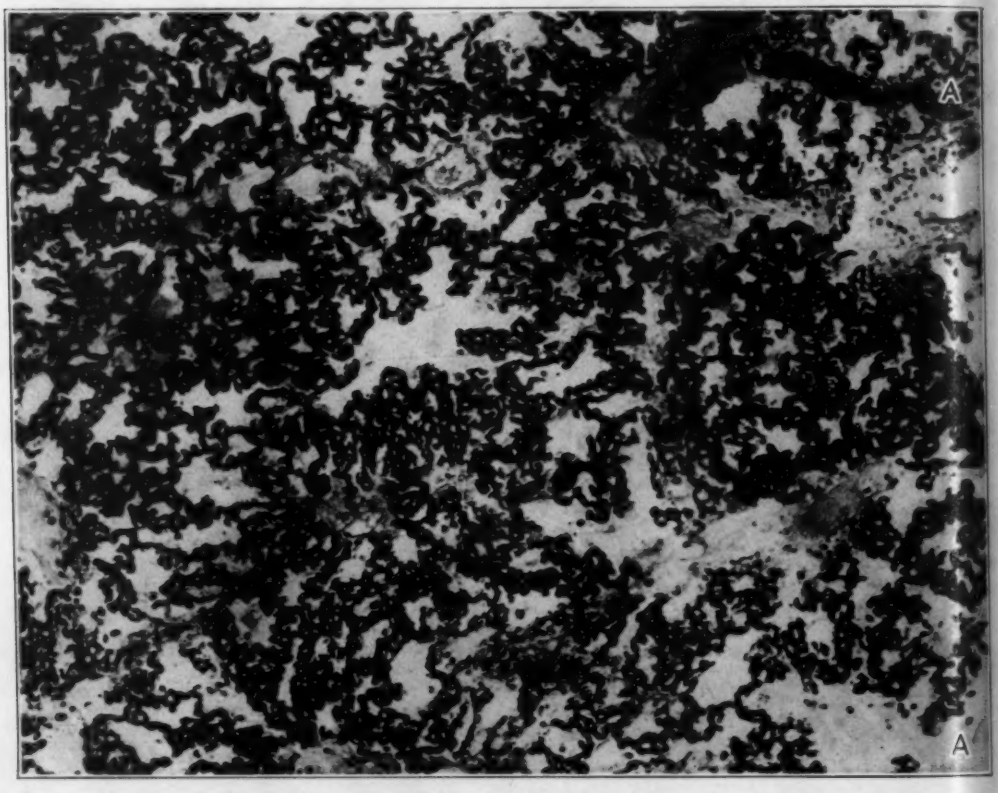

Fig. 27 (dog B 83).—Injection of india ink. Stage of incomplete atelectasis. Some alveoli with air are still visible, though the majority of them are shrunken and the capillaries tortuous.

the lung. We must inquire whether this conception of gradual and progressive circulatory impairment in the consolidated lung already severed from ventilation is in accordance with the modifications in the gas exchanges already noticed by other investigators in various cases of bronchial obstruction.

It is obvious that to the group of apneumatic lungs, in which after complete obstruction of a bronchus, absorption of the alveolar air and

collapse of the alveoli occur, we should add the cases in which partial obstruction of the respiratory ways produces a distention of alveoli, which are partially cut off from ventilation. In this last group belong asthma and emphysema.

If our conception is right,[138] in these last cases circulation must remain intact or even be increased in the capillaries. Blood would circulate through channels insufficiently aerated and a marked reduction of oxygen with carbon dioxide retention in the blood should follow, because

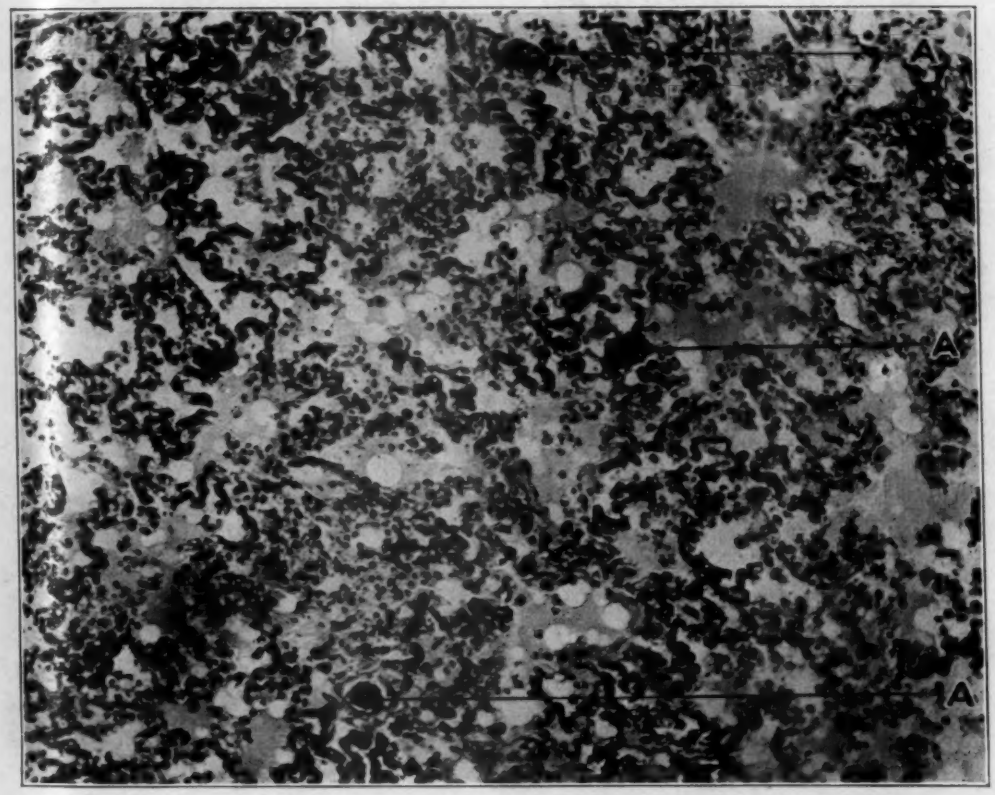

Fig. 28 (dog B 82).—More advanced stage of atelectasis. Few alveoli still contain air. Serous exudate is present. The capillaries are irregular and the blood content of the lung is certainly reduced; dilated arterioles are visible (*A*).

of the mixture of this unaerated with oxygenated blood. This is exactly what happens in asthma when bronchial spasm is extensive and involves the greater number of the bronchioli. Meakins has shown that in these cases the oxygen saturation of the arterial blood may be much below normal; an acute oxygen want with carbon dioxide retention develops, accompanied by pronounced hyperpnea and marked cyanosis.

In emphysema, where there is no bronchial obstruction but only impaired gas exchange because of structural changes in the respiratory channels of the lung (Hoover [21]), circulation is not affected. Oxygen want and carbon dioxide retention in marked cases are due to a relative stagnation of the alveolar air; this will have as a result a rise in carbon dioxide (from 60 to 63 mm. of mercury instead of 40 mm. of mercury) and a lowering of the oxygen partial pressure (from 70 to 75 mm. of

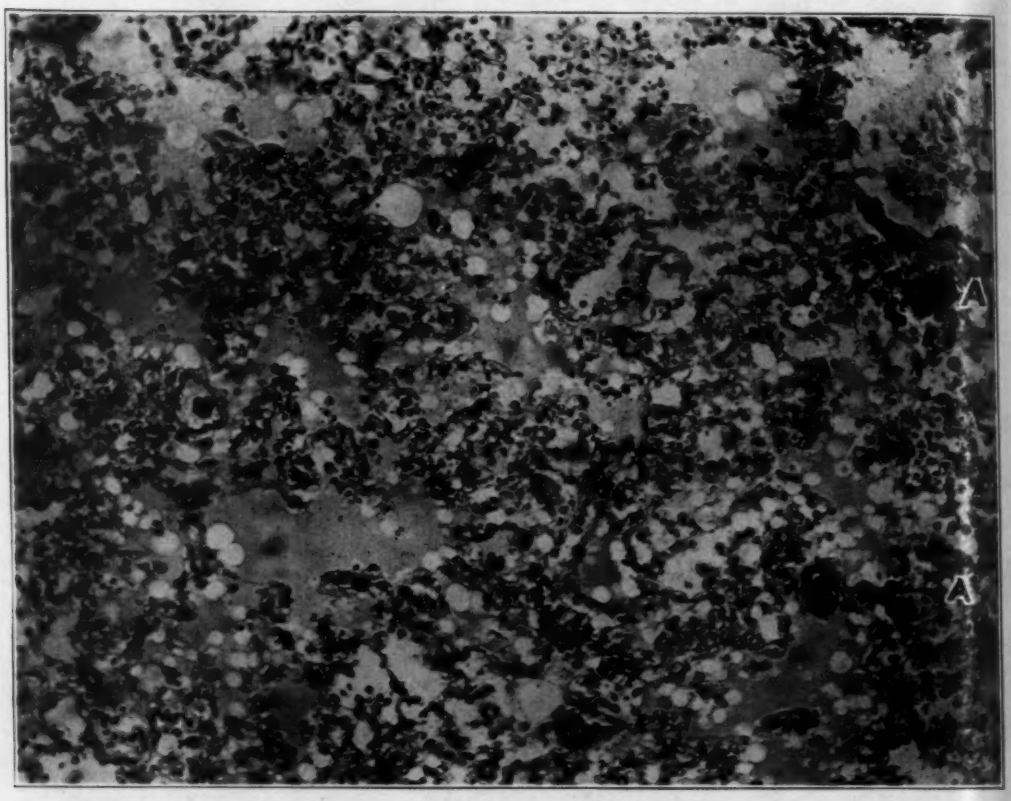

Fig. 29.—Atelectasis is more advanced than in figure 28. The circulation is markedly impaired. Dilated arterioles are visible (*A*).

mercury instead of 107 mm. of mercury) in the arterial blood. In both these diseases, as well as in acute edema of the lung, due, for example, to poisoning from phosgene gas (Winternitz and Lambert [139]), the capillary circulation is intact, and the ventilation alone is impaired. More or less acute oxygen want with carbon dioxide retention, increase

139. Winternitz and Lambert: J. Exper. Med. **39**:537, 1919.

in p_H and production of gaseous acidosis, is the characteristic modification in this group.

In opposition to the foregoing group are the conditions in which there is apneumatosis of a considerable portion of the lung. Atelectasis, bronchopneumonia and lobar pneumonia belong in the last category. Acute bronchitis would stand between this and the former group, representing a transitional form between them.

In fact, in uncomplicated acute bronchitis, there is no change in the blood gases. "If however the process extends to the finer bronchi and

Fig. 30 (dog B 52).—Roentgenogram of the chest taken twenty-four hours after insufflation of pneumococcus culture. Pneumonia of the left lung with complete shifting of the heart to the left and elevation of the left side of the diaphragm is seen. The clear space between the heart and the left side of the diaphragm is due to encroachment of the subcardiac lobe on the left side of the chest.

involves the bronchioli and the alveoli, signs indicating interference with the proper aeration of the arterial blood and retention of carbon dioxide may develop" (Meakins and Davies [107]). The degree of oxygen want will depend on whether "areas of lobules have been rendered non-functioning by closure of the bronchioli. As a consequence numerous small areas of the lung will be non-functionating, although a certain

amount of circulation will continue through these areas, in which oxygen tension will be reduced and venous blood will thus return to pollute the mixed arterial blood" (Meakins and Davies [107]). Between uncomplicated bronchitis and bronchopneumonia the only difference would be, according to these authors, the existence or not of areas of lung cut off from aeration by obstruction of the corresponding bronchi or bronchioli. Furthermore, Hoover [21] pointed out in 1918 the relation existing in these cases between blood flow and alveolar ventilation. Impairment of the circulation will follow bronchial obstruction and will gradually increase in parallel with the collapse of the alveoli. But in broncho-

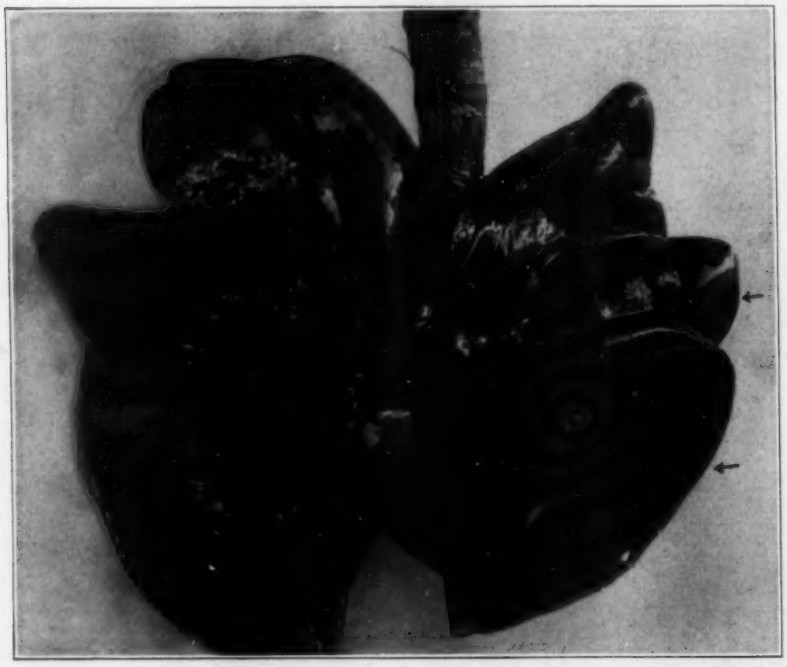

Fig. 31 (dog B 82).—Injection of india ink into the jugular vein. Photograph of the lung specimen showing it uniformly injected black. Arrows point to pneumonic lobe (twenty-four hour old process).

pneumonia as against lobar pneumonia, there is a dispersion of the process all over the lungs, those patchy consolidations occurring irregularly in time and distribution. The result is that in a great portion of the parenchyma of the lung, especially in the severe cases as observed in influenza epidemics, circulation will be maintained through unaerated channels; this fact explains that there is a pronounced oxygen unsaturation with increase in carbon dioxide content of the blood. In these cases the administration of oxygen does not relieve, or only partially

relieves, cyanosis, and it may be inferred, according to Meakins and Davies,[107] that "a blockage of the lobules of the lung with impaired circulation is so pronounced as to prevent penetration of the oxygen into the alveoli, in spite of its increased partial pressure. If the cyanosis is somewhat relieved, this would indicate that certain of the alveoli are only partially obstructed." (See cases 1 and 3 in table XIII of Meakins and Davies,[107] page 208.)

We have mentioned the modifications in the gas exchanges in bronchitis and bronchopneumonia because they show the gradual transi-

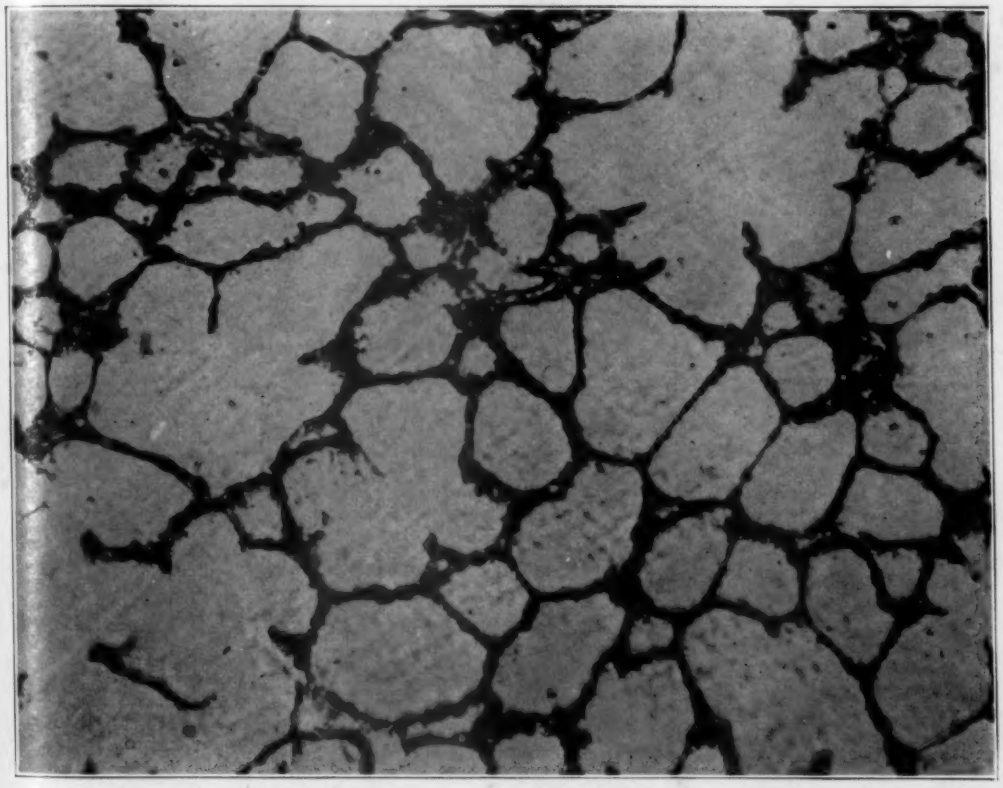

Fig. 32 (dog B 82).—Photomicrograph from the right upper lobe (normal). The alveoli are outlined by the capillaries which are well injected with india ink. No dilated vessels are visible.

tion from single bronchitis and bronchopneumonia and prove beyond doubt that occlusion of small bronchioli in the course of a bronchitis and the production of numerous patchy consolidations spread over the lungs determine interrelated changes in alveolar ventilation and capillary circulation, which give a simple explanation of the gas exchanges in these diseases.

In lobar pneumonia the same process occurs; but instead of a patchy and extensive distribution all over the lung, the process is strictly lobar. According to Meakins and Davies:[107]

> In the broncho-pneumonias the process is as a rule irregular in distribution and time. Thus various portions of the lungs become successively consolidated with obliteration of the alveoli. In lobar pneumonia a similar sequence of events occurs, but with this difference—that as a rule the pulmonary lesion progresses uniformly from partial to complete consolidation. It is therefore only when the disease is observed from its earliest manifestations or when different lobes are involved in succession that the process of events may be determined.

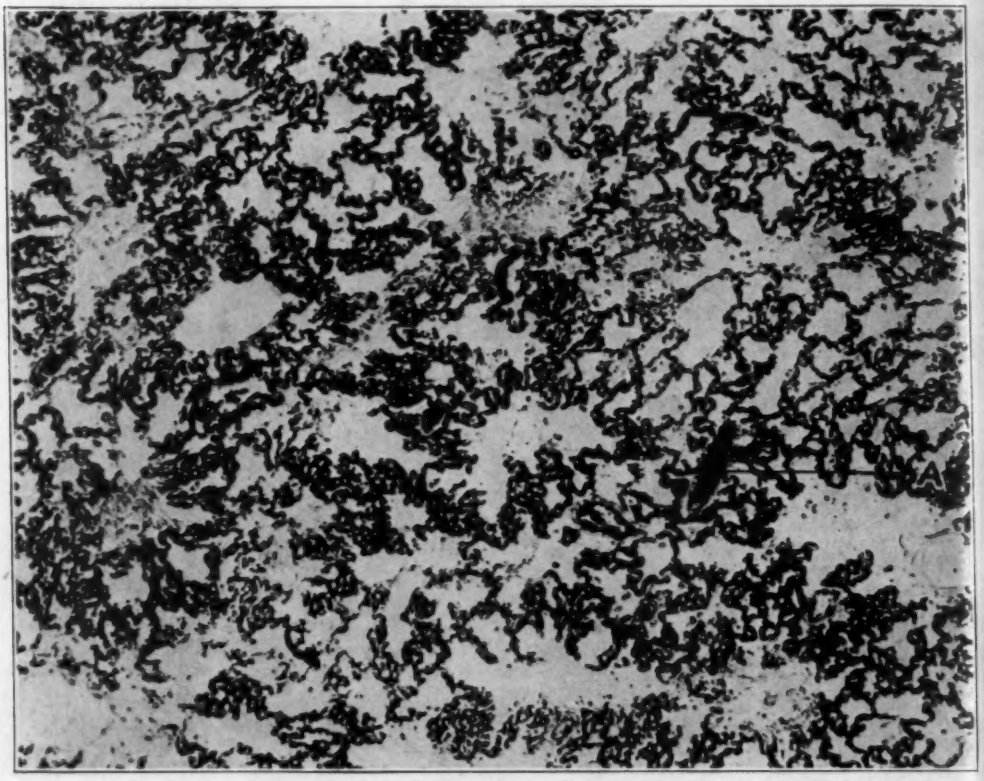

Fig. 33.—This photomicrograph corresponds to the period of "engorgement" and was taken from a part of the pneumonic lung which submerged but did not sink in water. The alveoli are shrunken. The few dilated vessels seen are terminal branches of the pulmonary artery (*A*).

We have maintained in previous papers[185] that the nature of the process is the same in bronchopneumonia or lobar pneumonia, the only difference being in the size of the occluded bronchi; and that from the standpoint of pathogenesis, bronchopneumonia bears the same relation to lobar pneumonia that patchy atelectasis bears to lobar atelectasis.

The altered gaseous exchange in pneumonia is an additional proof of this conception. In the early stages of pneumonia there is anoxemia combined with increase in carbon dioxide in the blood. In a case in which Meakins and Davies [107] had the rare opportunity to make observations before and after the disease (case 12, table xviii, page 226), they found in the arterial blood:

	O_2 per cent saturation of blood	*CO_2 per 100 cc. of blood*
Before the onset	95	52
Second day of disease	89	67
Sixth day of disease	84	45
Seventh day of disease	93	47

Barach and Woodwell [140] reported a similar case, in which they noticed a sudden increase in carbon dioxide (from 53 to 61 per cent by volume) of the arterial blood coincident with the involvement of an additional lobe of the lung. Binger and Davis,[141] in their case 15 (page 181), that of a young patient in the second day of pneumonia involving the middle and lower right and lower left lobes, failed to notice any changes in the oxygen saturation of the arterial blood although they had him in the oxygen chamber in an atmosphere of 40 per cent oxygen for more than an hour. They concluded that "in this instance we must assume that blood was circulating through unaerated portions of the lung, and that this rather than shallow breathing was in the main responsible for oxygen want." Case 16 of the same authors is similar to case 15. Unfortunately, the carbon dioxide content of the arterial blood is not given in these cases; both patients died on the second and fourth day after admission, respectively.

The high carbon dioxide content in the initial stages of lobar pneumonia is explained by Meakins and Davies [107] as being "due to early alveolar inflammation and interference with function occurring before the pulmonary circulation in these areas was grossly interfered with. There would therefore be a probable pollution of the arterial blood with venous blood rich in carbon dioxide." But although these authors accept that "the cases of broncho pneumonia are also of this type" (page 237), and that "the same conditions are operative in red hepatization of lobar pneumonia as exist in broncho pneumonia," they failed to see the identity of the pathogenesis in the two conditions, namely, bronchial obstruction. Our photomicrographs of the circulation in the early stages in lobar pneumonia show clearly this partial persistence of circulation.

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140. Barach and Woodwell (footnote 122, first reference).

141. Binger, C. A. L., and Davis, J. S.: The Relation of Anoxemia to the Type of Breathing in Pneumonia, J. Clin. Investigation **6**:171 (Oct.) 1928.

On the contrary, as the process advances, the circulation in the consolidated lung will become more and more impaired. The amount of blood circulating in unaerated channels will be negligible, so that the percentage of carbon dioxide in the arterial blood will fall and that of oxygen rise toward normal. It is not within the scope of this work to discuss the relation between anoxemia, carbon dioxide content and shallow breathing. The only point which interests us is the increase

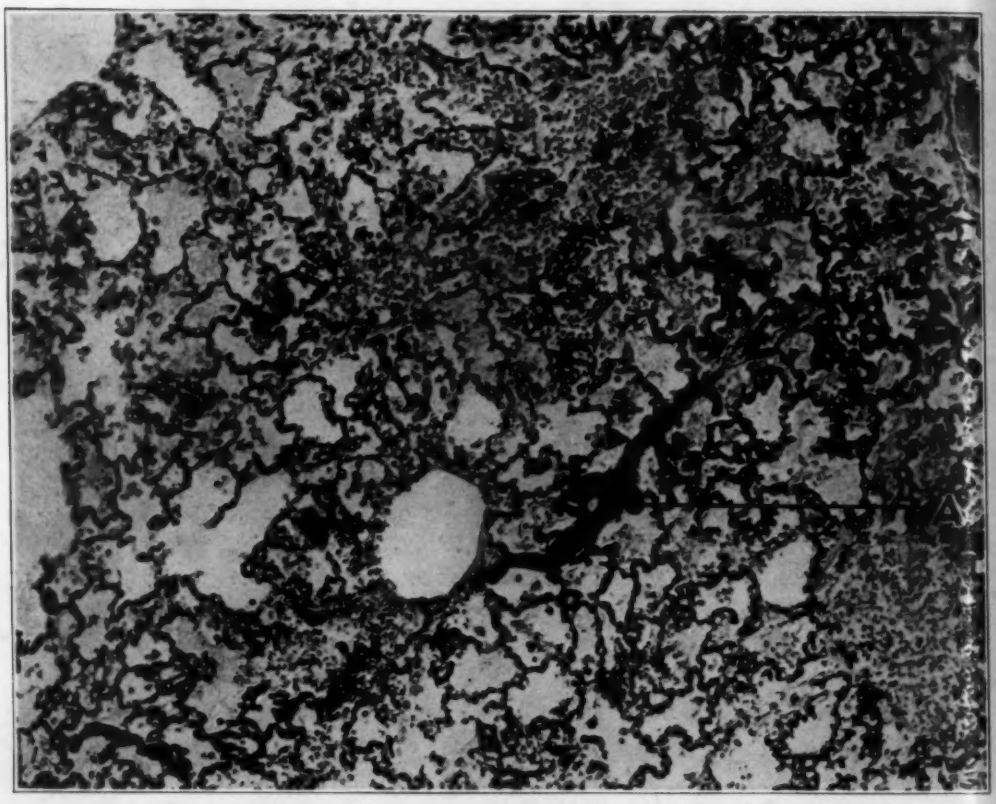

Fig. 34.—A more advanced process with exudate in the alveoli. Capillary circulation is still more impaired. Dilated pulmonary arterioles are clearly visible (*A*).

of carbon dioxide and fall in oxygen in the initial stages of lobar pneumonia and the decrease in carbon dioxide in the later stages of the disease.

These facts put beyond discussion the existence of a progressive circulatory impairment in lobar pneumonia, of the same type as in bronchopneumonia. This gradual circulatory impairment can be explained by the mechanism we proposed rather than the one proposed

by Binger [141] or Kline and Winternitz.[12] It is interesting that Binger and Brow [136] remarked that "a close parallelism has been observed in radiographic shadow, physical signs and the volume of the functional residual air. The lung volume measured at normal expiration is diminished during the persistence of pathological signs in the lungs and returns to normal as the pathological signs disappear. The average time required, in cases which recovered, for the functional residual air to

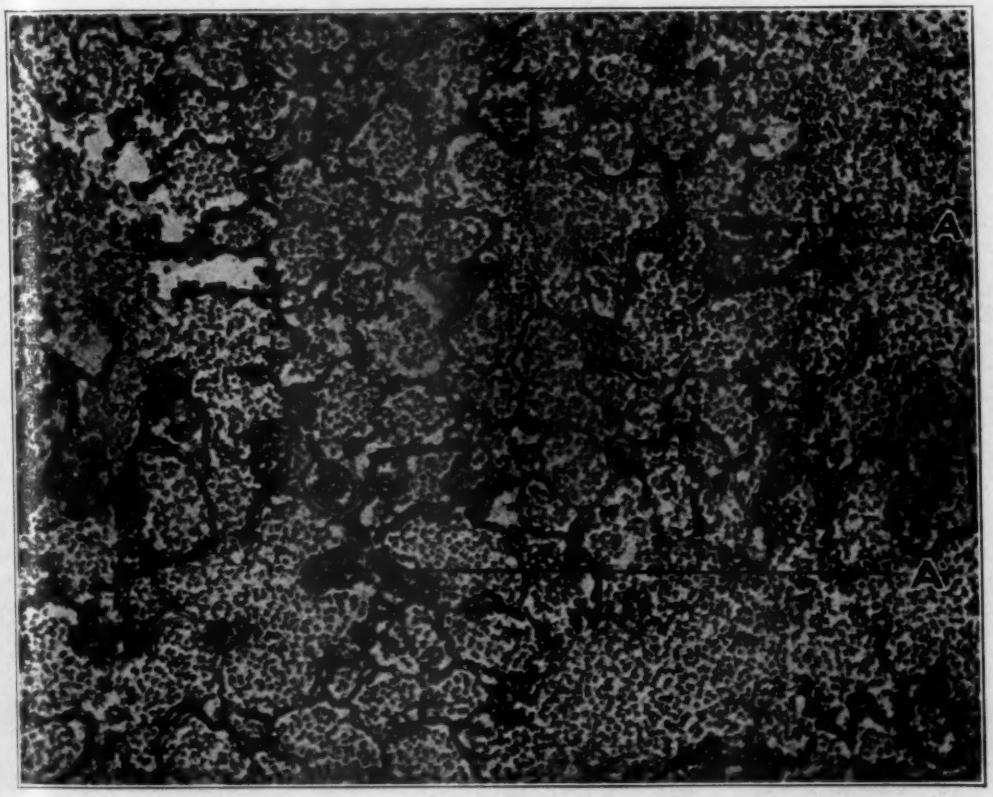

Fig. 35.—Stage of red hepatization (stained preparation). Capillaries are more irregular; there are large areas without capillaries. Dilated arterioles are clearly seen (*A*).

become constant was 11-12 days, counting from the onset of the disease." This being the case, it is difficult to understand how the cause of circulatory impairment would be the pressure exerted on the capillaries by the intra-alveolar exudate, and how the lung during the period of capillary compression would be smaller than under normal conditions. Likewise, the theory of thrombosis or embolism of the pulmonary vessels is untenable, for during red hepatization, when the fibrinous

process is at its height the circulatory impairment is conceded to be less pronounced than in gray hepatization.

Our conception, on the contrary, explains the progressive impairment of the circulation and is supported by facts demonstrable by simple experimental methods.

COMMENT

The observations given previously represent only a small part of our experimental investigation. We purposely refrain from mentioning

Fig. 36.—Stage of early gray hepatization. Capillary circulation is greatly impaired. The capillaries are broken up and sections of dilated arterioles are seen (stained preparation). Dilated arterioles are marked *A*.

results obtained with injections into the jugular vein of sodium iodide, vital stains, gelatin with radiopaque substances or even mercury. Experiments with these substances gave us a good insight into the causes of incomplete injections of the pulmonary tree of other authors which led to inaccurate conclusions. Gross,[13] Binger [142] and his collabo-

142. Binger and others (footnotes 132 and 136).

rators and Kline and Winternitz [12] have fallen into error on similar account. Postmortem injections into the lung, particularly in pneumonia, of gelatin or celloidin containing masses have failed to yield uniform injections. The incomplete injection may occur in a healthy lobe as well as in an involved one but more frequently in the latter because of postmortem thrombosis occurring more rapidly in the pneumonic than in the healthy lobe.

As our experiments have shown, it is important to distinguish branches of the pulmonary artery from the capillaries, when considering impairment of circulation in the lung rendered apneumatic from whatever cause. That is, the circulation in the arterioles is not impaired whereas in the capillaries it is. Moreover, when we talk about "an angiomatous condition" of an atelectatic lung we must remember that the capillary circulation is distinctly impaired in direct proportion to the degree of shrinkage and airlessness; however, because of this capillary impairment, there is a stasis in the small precapillary arterioles of the pulmonary atreries, and it is these arterioles which appear dilated in microscopic sections. In all our sections this fact was clearly visible. This fact is consistent with those roentgenograms of the chest taken during the injection of iodized oil into the jugular vein, which show the branch of the pulmonary artery corresponding to the involved lobe to be dilated.

We have given reasons for which we believe that the theories of thrombosis and embolism in the capillaries and arterioles of the pneumonic lung should be discarded. Thrombosis in the living human being or animal has never been proved nor has an acceptable explanation been given of the rapid restitution to normal of such large volumes of the pulmonary tissue in uncomplicated pneumonia.

The theory of compression of the capillaries by intra-alveolar exudate we believe to be no longer tenable. It is clearly shown in our photomicrographs that the alveoli filled with exudate are smaller than the normal ones.

The circulatory impairment in both the atelectatic and the pneumonic lung has been shown to be strikingly similar. This would point to a similar mechanism of production of such impairment, would explain the rapid reestablishment of the capillary circulation after aeration of the parenchyma of the lung in both diseases and would explain the absence of any marked lesions in the pulmonary tissue after recovery in uncomplicated cases.

These experimental, pathologic and clinical considerations lead us to make the following statement:

Circulatory changes are similar in the compressed atelectatic and consolidated (pneumonic) lung. They do not affect the pulmonary arterial tree but are exclusively limited to the capillaries. This capil-

lary impairment is not complete, blood in very reduced amounts circulating in the affected lung. It is proportionate to the degree of atelectasis and is due exclusively to the mechanical shrinkage accompanying the process of apneumatosis (atelectasis)—whatever the cause of this airlessness may be.

CONCLUSIONS

1. A new method for the study of the arterial and capillary circulations in the lung has been presented—intrajugular injections of iodized oil for the arterial circulation and Ringer's solution and india ink for the capillary circulation.

2. Circulation and ventilation of the lung are parallel functions; when ventilation is impaired circulation is decreased, and conversely.

3. In the compressed, atelectatic (apneumatic) and consolidated lung, the circulation is progressively impaired. This impairment is due to, and regulated by, the degree of collapse of the alveoli, and not to capillary thrombosis or capillary compression by alveolar exudate as heretofore believed.

4. Lobular pneumonia is comparable to lobular atelectasis and lobar pneumonia to lobar atelectasis; the circulatory changes are exactly the same, and they are related to impaired ventilation due to occlusion of a lobular or lobar bronchus with exudate; their clinical severity depends on the virulence of the microbes concerned.

5. In pneumonia and atelectasis, strikingly similar pictures are obtained so far as the evolution of circulatory impairment is concerned.

6. Only the capillary circulation is involved. Circulation in the pulmonary arterial tree is not affected. The capillary impairment is not complete.

7. Modifications in the gas exchange in pneumonia (oxygen and carbon dioxide) corroborate our experimental observations and theory.

8. Changes observed in the size of the alveoli in lobar pneumonia offer a new proof in favor of views, previously developed, that bronchopneumonia and lobar pneumonia should be considered as the infectious variety of patchy or lobar atelectasis, respectively.

ADDITIONAL BIBLIOGRAPHY

Anderes, E., and Cloetta, M.: Eine weitere Methode zur Prüfung der Lungenzirkulation, Arch. f. exper. Path. u. Pharmakol. **79**:291, 1915.

Die Beweis für die Kontraktilität der Lungengefässen, Arch. f. exper. Path. u. Pharmakol. **79**:301, 1916.

Blumer, G.: Bedside Diagnosis, Philadelphia, W. B. Saunders Company, 1928, vol. 2, pp. 155, 160 and 171.

Bohr, C.: Ueber die Lungenatmung, Skandin. Arch. f. Physiol. **2**:236, 1890.

Blutgase und respiratorische Gaswechsel, in Nagel: Handbuch der Physiologie des Menschen, 1905, vol. 1, p. 187; Centralbl. f. Physiol. **71**:688, 1904.

Brodie, T. G., and Dixon, W. E.: Contribution to the Physiology of the Lungs, J. Physiol. **30**:476, 1904.

Dale, H. H., and Richards, A. N.: The Vasodilator Action of Histamin and of Some Other Substances, J. Physiol. **52**:110, 1918-1919.

De Jager, S.: Welchen Einfluss hat die abdominal Respiration auf den arteriellen Blutdruck? Arch. f. d. ges. Physiol. **33**:17, 1883.

Donders, F. C.: Physiologie des Menschen, ed. 2, Leipzig, S. Hirzel, 1859.

Drinker, C. K.; Peabody, F. W., and Blumgardt, H. L.: The Effect of Pulmonary Congestion on the Ventilation of the Lungs, J. Exper. Med. **35**:77, 1922.

Funke, J.: Embolism and Thrombosis of the Pulmonary Artery, M. Rec. **79**: 673, 1911; Proc. Path. Soc., Phil., n. s. **13**:249, 1910.

Gerhard, D.:. Ueber den Druck in Pleuraexudaten, Arch. f. exper. Path. u. Pharmakol., Festschrift fur Schmiedeberg, Suppl., 1908, p. 228.

Henderson, Y., and Harvey, S. C.: Am. J. Physiol. **46**:533, 1918.

Henderson, Y., and Scarbrough, M. M.: Am. J. Physiol. **26**:260, 1910.

Henderson, Y., and Underhill, F. P.: Am. J. Physiol. **28**:152, 1911.

Hinman, F.; Morrison, D. M., and Lee-Brown, R. K.: Methods of Demonstrating the Circulation in General, J. A. M. A. **81**:177 (July 21) 1923.

Jerusalem, E., and Starling, E. H.: On the Significance of Carbon Dioxide for the Heart Beat, J. Physiol. **40**:279, 1910.

Karsner, H. T.: Nerve Fibrillae in the Pulmonary Artery of the Dog, J. Exper. Med. **14**:322, 1911.

Litten, M.: Untersuchungen über hemorrhagischen Infarkte, Ztschr. f. klin. Med. **1**:131, 1880.

Meakins, J. C.: J. Path. & Bact. **42**:79, 1921.

Miller, W. S.: The Vascular Supply of the Pleura Pulmonalis, Am. J. Anat. **7**:389, 1907.

Pannum, P. L.: Experimentelle Beiträge zur Lehre von der Embolie, Virchows Arch. f. path. Anat. **25**:308, 1862.

Parsons, A. R., and O'Sullivan, A. C.: Anemic Infarct of the Lung, Tr. Roy. Acad. M. Ireland, Dubl. **28**:393, 1910.

Stadelmann, E.: Ueber Thrombose der Pulmonalarterien, Deutsche med. Wchnschr. **25**:1089, 1909.

Tiedemann, E.: Pathologischanatomische Studien für die klinische Diagnostik des hemorrhagischen Lungeninfarktes, Ztschr. f. klin. Med. **1**:27, 1903.

Tigerstedt, R.: Die Geschwindigkeit des Blutes in den Arterien, Ergebn. d. Physiol. **4**:484, 1905.

Tuffier and Hallion: Etude expérimentale sur la chirurgie du poumon, Compt. rend. Soc. de biol. **48**:1047, 1896.

Sur la regulation de la pression intrabronchique, Compt. rend. Soc. de biol. **48**: 1086, 1896.

Wood, H. C.: Studies of Pulmonary Circulation, J. Exper. Med. **14**:326, 1911.

ABSTRACT OF DISCUSSION

Dr. Emil Holman, San Francisco: As I understand Dr. Coryllos, he found no disturbance of the gross injection of the hemorrhagic consolidated lobe. In our injections, we found a definite cutting off of the vessels, a blocking of the entire precapillary circulatory bed. From his injections, there seems to be no difference at all.

We did not study microscopically the areas into which the injections were made. We felt that the filling up of the alveolar spaces and the closing up of

these alveolar spaces resulted in diminished circulation through the capillaries of the lung, and certainly through the precapillary circulatory bed.

DR. P. N. CORYLLOS, New York: I think that this discrepancy is due to the facts that we used iodized oil for our injections, and that we injected it into living animals and not dead ones, as in the experiments of Cross, Binger and his collaborators, and others. Iodized oil mixes with the blood and penetrates down into the smallest branches of the pulmonary artery, if the animal survives for a sufficient time after the injection. A minimum of from two to three minutes seems necessary for a successful injection. It is easy to understand that in injections into the pulmonary artery, on the dead animal with radiopaque substances, especially in suspension in gelatin, an obstruction of an important branch of the pulmonary artery can easily occur. This cause of error is eliminated, we believe, when the injections are made into the jugular vein of the living animal, without pressure and with a nontoxic substance; this passes through the jugular into the right side of the heart, which takes charge of its distribution into the lung. We are thus placed in conditions as near the normal as possible, and therefore we believe that the results obtained by this method may be considered as reliable.

THE SURGICAL TREATMENT OF BRONCHIAL ASTHMA*

EDGAR W. PHILLIPS, M.D.
AND
W. J. MERLE SCOTT, M.D.
ROCHESTER, N. Y.

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THE PROBLEM OF THE UNRELIEVED ASTHMATIC PATIENT

The discovery of an allergic basis for certain cases of bronchial asthma and their striking cure based on this knowledge present one of the most fascinating chapters of modern medicine. However, this advance serves by contrast to emphasize the hopeless condition of those numerous unfortunate persons whose attacks continue unabated in spite of all medical treatment. As in other fields, the failure to relieve such sufferers has stimulated a far reaching search for alleviation. Thus, recently roentgen treatment has been added to the therapeutic possibilities for the internist. In certain instances roentgenotherapy has apparently been effective, but in many cases it, too, has failed. Pioneer surgeons also have attempted to solve the problem by using anatomico-physiologic knowledge developed by experimentation. Although certain surgical interventions for the relief of asthma, chiefly those directed toward the mobilization of the wall of the chest, date back for a considerable period of time, it is only within the last six years that an attempt has been made to influence a possible nervous control of the paroxysm. In this short interval, however, a number of operations have been tried which present important theoretical and practical phases. Several hundred cases of bronchial asthma in which operation was performed have now been mentioned in the literature, and a sufficient interval since the earliest of these now exists to allow a careful analysis of the results that have been obtained. Although in America

* From the Department of Surgery, the University of Rochester School of Medicine and Dentistry and the Rochester General Hospital.

fundamental contributions on the allergic basis of asthma have been made both in the experimental field and in the clinical applications of this knowledge, scant attention has been paid here to the possibilities of surgical assistance. And no adequate survey of the operative treatment for bronchial asthma is available in the American literature. It is our purpose in this paper to consider briefly the theoretical basis for such surgical interventions and to analyze the results so far obtained. We will discuss the mechanism of the asthmatic attack and the innervation of the lung only so far as they directly affect the rationale of the operative treatment. We recommend Alexander's [1] monograph on bronchial asthma for those interested in a detailed discussion of its pathogenesis, and Braeucker's [2] study of the extrinsic pulmonary nerves.

MECHANISM OF THE ASTHMATIC PAROXYSM

In attempting to relieve the paroxysms of dyspnea which characterize bronchial asthma by an operation on the extrinsic nerve supply of the lungs, it must be admitted at once that theory rather than fact is the basis from which the therapy originated. It is generally accepted that a diminished caliber of the finer air passages is the direct cause of the dyspnea. There are three factors that have been considered as possibilities in producing such a bronchial narrowing: (1) spasm of the intrinsic muscles, (2) mucosal swelling and (3) abnormal secretion. (The term "bronchial" here and elsewhere in this paper is used in its generic sense. It is intended primarily to signify the site at which partial stenosis may occur in the asthmatic paroxysm. The evidence is inconclusive whether this may be chiefly in the small bronchi or in the bronchioles.)

Bronchospasm.—The oldest theory, namely, bronchospasm, dates back at least to the early seventeenth century when Helmont [3] suggested the "drawing together of the smallest bronchi" as the cause of the paroxysm, although the definite demonstration of the bronchial muscle came nearly two hundred years later in the classic work of Reissiesen [4] (1822). After this discovery of a constricting mechanism in the respiratory tree, most investigators have taken it for granted that muscle spasm plays the predominant rôle in producing the asthmatic attack. This belief has been particularly strengthened by numerous experiments showing bronchial constriction on vagus stimulation. The original crude but ingenious methods of Wedemeyer [5] in 1828 and Williams in 1840 [6] have been verified with greatly refined methods. However, when scrutinized from the point of view of proving that bronchospasm rather than mucosal swelling is the cause of the asthmatic paroxysm, little evidence has been offered. Most of the physiologic work in this field has determined only the increased resistance to air

movement through the respiratory tree after nerve stimulation and has not proved that nerve impulses acted on the bronchiolar muscle. In 1922 Huber and Koessler [7] demonstrated hypertrophy of the bronchial muscles in asthma. This, in our opinion, is the most effective evidence in favor of the theory of bronchospasm. It is interesting that Strümpell,[8] who favored mucosal swelling, stated in 1908 that the best proof of the bronchospastic theory would be such a demonstration. Most of the other facts that have been adduced in support of it, such as the therapeutic effect of atropine and epinephrine, can equally well be explained as due to a reaction on the vessels, the mucous membrane or the glands of the finer air passages.

Mucosal Edema.—Influenced by the character of the râles, Beau,[9] in 1848, suggested mucosal swelling as the cause of the asthmatic paroxysm. This has been advocated by Blackley,[10] Strümpell,[8] Solis-Cohen [11] and others in correlating the fundamental pathologic process of asthma with that of urticaria and angioneurotic edema. This theory received rather scant attention until the recent important discovery of the allergic basis for at least certain types of asthma. Coca [12] particularly stressed the point that the outstanding pathologic lesion of atopy is edema. Consequently, he felt that swelling of the mucous membrane cannot be lightly dismissed. There is little direct evidence in its support. Postmortem examinations showing edema do not have the same weight as the demonstration of muscle hypertrophy because the former may be rapidly produced as a terminal complication, while the latter is evidence of a long continued process. Several bronchoscopic observers have found mucosal congestion and edema during an asthmatic paroxysm (Yankauer [13] and Ephriam [14]). Because of the observation of mucosal swelling in the large bronchi, it is inferred that a similar condition exists in the smaller air passages. This inference is the only basis on which such observations can have any bearing on the cause of the paroxysm.

Secretion.—The characteristic sputum which frequently accompanies or follows a paroxysm of bronchial asthma has caused several authors to suggest an abnormal secretion as assisting mucosal swelling in the bronchostenosis. Curschmann,[15] in 1883, suggested that the formed elements described by him played an important rôle in producing dyspnea. The exact significance of abnormal secretion in asthma is not known.

Summary.—Although the controversy over the mechanism of the asthmatic attack has been going on for a great many years, we seem no nearer a final decision in favor of any one hypothesis. In fact, there is strong presumptive evidence for each factor: bronchospasm, mucosal swelling and abnormal secretion (to a less extent). These factors are

probably present together in varying degrees. Consequently, we must freely admit that the underlying mechanism which produces the paroxysmal dyspnea is not definitely known. But all investigators agree that it acts by interfering with the freedom of air movement through the finer respiratory passages.

THE BRONCHOMOTOR NERVES OF THE LUNGS

All the factors that were discussed in the preceding paragraphs as possible causes of the asthmatic dyspnea are, at least in part, under the control of the extrinsic pulmonary nerves. It is this fact that has given rise to the hope that nerve interruption might benefit the disease. The various operations used have been grounded on the imperfect but increasing understanding of the complicated nervous connections and of the effects of stimuli traversing them. Consequently, it is important to review the present state of the knowledge concerning the anatomy and physiology of the nerve supply to the lung.

The vagus had long been considered the sole bronchomotor nerve of the lung. Stimulation of the distal cut end of the vagus causes bronchoconstriction on the same side (Longet [16] and Dixon and Brodie [17]) and to a less extent on the opposite side (Weber [18] and Braeucker [2]). This proves bilateral innervation. The specificity of parasympathetic stimulation in these observations may be questioned, as the experiments on which they are based were carried out in animals having a combined vagosympathetic trunk. It has been emphasized by Braeucker and Kümmell [19] that, in the dog at least, electrical stimulation limited to the vagus can only be obtained by application of the electrode to the nerve trunk within the skull. They found the result of such a stimulation to be usually constriction but occasionally dilatation or alternating constriction and dilatation. They admitted that this is not definite proof of two types of fibers in the vagus but that it might result from a difference in the tonus of the intrapulmonary autonomic plexus at different times. They regarded this plexus as the direct controlling motor center of bronchospasm.

The rôle of the sympathetic system in pulmonary innervation is even less clear. Unfortunately, from the point of view of simplicity, the schematic conception of the antagonism supposed to exist between the vagus and the sympathetic is inadequate to explain the known facts of lung innervation. Braeucker [2] stated that there are as many sympathetic fibers as vagal entering the posterior pulmonary plexus. Two theories are given in explanation of the beneficial effect of sympathetic interruption in the treatment of asthma: first, that bronchoconstrictor fibers run in the sympathetic chain as well as in the vagus, and second, that the sympathetic is the afferent side of a reflex arc. Kümmell's [20] original operation on the extrinsic nerves for asthma was based on the

first theory. Dixon and Ransom [21] obtained bronchoconstriction by sympathetic stimulation in cats, and Braeucker [2] has amplified this in the dog. Papilian and Cruceanu [22] found in animals a decrease of the respiratory volume of one-half for from eight to ten days following cervical sympathectomy or painting the ganglions with 1 per cent nicotine. Weber [18] showed that the bronchoconstrictor action of pilocarpine was prevented only after section of both vagi and the cervical cord. Fründ [23] thought that the vagus and the sympathetic represent parts of the same vegetative nervous system, divided into tracts by more or less casual considerations, and one or the other may carry the principal mass of tonus-stimulating fibers. There is a wealth of opinion but a decided lack of fact in support of the second theory; namely, that the sympathetic is the afferent limb of a reflex arc of which the vagus forms the efferent or motor portion. Kaess,[24] Glaser,[25] Hesse,[26] Jungmann and Brüning [27] and Witzel [28] have assumed this theory. There is a close parallelism between the reflex arc hypothesis with interruption on the sensory side in bronchial asthma and the corresponding explanation offered for the operative results in angina pectoris. Gross anatomic study of the pulmonary nerves has long established the dual innervation to the lung. The finer histologic investigation has shown that the lung, like all other viscera supplied with autonomic motor nerves, has also an intrinsic (and probably automatic) system. The anatomic arrangement is most bewildering. The main bundles from the vagus are joined by numerous minute filaments from the sympathetic chain and from other intrathoracic plexuses and redistributed in a succession of bronchial and submucous plexuses. It is fortunate that apparently all those extrinsic nerve paths which control the caliber of the finer air passages are condensed in the posterior pulmonary plexuses.

Fontaine, and Hermann [29] preface their experimental study of denervation of the lung by a good review of the literature concerning the nervous structures in the lungs and their extrinsic connections. Remak,[30] in 1840, described separate ganglions among the fibers of the pulmonary plexuses. It was later shown by many observers that some of these ganglions are present in the bronchial walls and that there is a system of fine nerve fibers connecting them (Kandarazki [31] and Larsell [32]). Fründ [23] classified asthma into two groups, depending on the location of the stimulus producing bronchostenosis, (1) extrapulmonary and (2) intrapulmonary, and concluded that operation might do good in the first group. Braeucker [2] said that bronchospasm may theoretically occur after section of the posterior pulmonary plexus from stimulation of the ganglions in the bronchi either from the blood or through an intrapulmonary reflex arc. Brüning,[33] in 1927, expressed himself as favoring an intrapulmonary reflex. Herrmannsdorfer,[34]

in discrediting operations on the vegetative system for bronchial asthma, stated that the many allergens which can induce asthma do so without invoking the extrinsic vagosympathetic mechanism. The success of nerve-interrupting operations in the treatment for bronchial asthma rests chiefly on the hypothesis that the activating agent of the bronchostenosis does not produce its effect by a direct action on the bronchial mucosa or the peripheral nerve mechanism.

The many good and lasting results obtained seem to us strong evidence that in certain instances interruption of extrinsic nerve con-

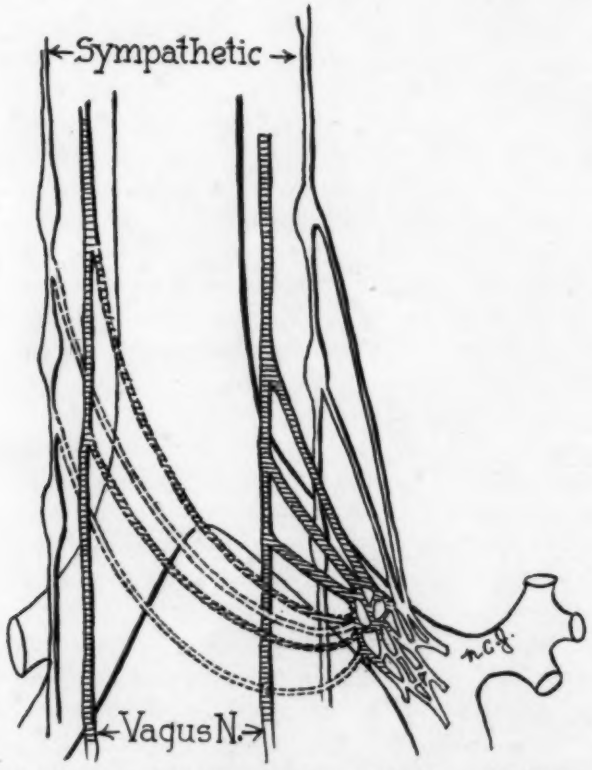

Fig. 1.—Schematic representation of the participation of both the sympathetic and the vagus fibers from the same side and from the opposite side in the formation of the posterior pulmonary plexus (according to Braeucker's experiments).

duction interferes with subsequent bronchostenosis. It is not known whether this acts by disconnecting the intrapulmonary muscles, vessels and glands from the central nervous system or by modifying in some manner the action of the intrinsic nerves.

Summary.—The rôle played by the extrinsic nerves of the lung in an asthmatic paroxysm is no clearer than is the local condition in the air passages that actually produces the stenosis. It is fair to state that there seems to be a bisystem, bilateral nerve supply to each lung, the

tracts of which are carried through the vagus and the sympathetic systems (fig. 1). The preponderance of opinion is in favor of the vagus as the main bronchomotor nerve. There is ample evidence that bronchostenotic fibers are also carried over the sympathetic. That the sympathetic fibers are the inner or afferent side of a reflex arc is theoretically attractive without many known facts for its foundation.

OPERATIONS FOR BRONCHIAL ASTHMA

Operations on the Extrinsic Nerves of the Lung.—In 1923, Kümmell [20] surprised the surgical world by reporting immediate relief following the first intervention on the extrinsic nerve supply of the lung for bronchial asthma. He based his operation on the attempt to reduce bronchospasm by a decrease in motor innervation. He realized that the vagus was the chief motor nerve to the lung but feared the consequences of cutting it. Therefore, believing that some of the motor fibers of the vagus passed to the lung over the sympathetic, he performed a unilateral cervical sympathectomy. He apparently thought that in this way he would diminish the bronchospasm by weakening its innervation. Braeucker [2] in Kümmell's clinic then conducted anatomic and physiologic studies on the motor nerve paths to the lung. He found that stimulation of either the vagus or the sympathetic caused, at least at times, an increased resistance to the interchange of air. In other words this effect, commonly regarded as proof of bronchospasm, is represented in both systems. These data offer a more reasonable explanation for a possible diminution in the motor innervation following sympathectomy, and this explanation has been adopted by Kümmell.[20]

Stimulated by the extremely optimistic report of Kümmell's first series many German, Russian and French surgeons began removing various parts of the cervicothoracic sympathetic system. As would be expected from such a wave of enthusiasm for an entirely new method of attacking asthma, the most varied results were recorded. Most of the brief reports of a few isolated cases that appeared in 1924 and 1925, though probably of some use at that time, are of practically no value in analyzing the operative results. They were prepared with too little data in regard to the conditions present. An even more unfortunate occurrence, the patients reported had been followed for too short an interval, in some instances only two weeks and usually not more than four months. Under such conditions it is obvious that many operations were carried out in entirely unsuitable cases, as, for example, instances of dyspnea due to cardiac insufficiency or to glandular involvement at the hilum. Also, the degree of completeness with which the sympathetic paths to the lung were interrupted was extremely variable. Even from the scant descriptions given of the operative technic, it was clear that many of these sympathectomies were incomplete. Even if complete removal of the stellate ganglion is achieved, sympathetic stimu-

lation reaches the homolateral lung, as the rami communicantes send fibers to it from as low as the fourth thoracic root (Braeucker[2]). One of the most striking facts about interventions on the sympathetic system for asthma has been the absolute divergence of their results in different clinics. Some investigators reported most encouraging results, while others saw no lasting benefit. Probably the selection of cases accounts for part of these differences. It seems to us impossible, however, to reconcile the complete lack of success of some with the brilliant and lasting results obtained by several in certain desperate cases except on the basis of incomplete application of the methods and technic advocated by the originators of these operations. On the other hand, it is equally obvious that sympathectomy is not a panacea for the relief of all dyspnea or even of all cases of idiopathic bronchial asthma.

Kümmell[20] removed the cervical sympathetic chain together with as much of the stellate ganglion as he could reach. Leriche and Fontaine,[35] on the other hand, felt that there was no necessity of removing more than the stellate ganglion. They operated through a cervical incision, though they suggested a thoracic attack on the sympathetic communications to the lung. So far as we have been able to ascertain, they have never carried out the latter procedure.

In a few instances bilateral cervical sympathectomy has been performed either at one sitting or with a short interval. The rationale of this procedure is that unilateral sympathectomy affects chiefly the nerve paths of the homolateral lung; consequently, the conditions on the other side are slightly changed. The year following Kümmell's first sympathectomy, Kappis[36] reported equally encouraging immediate results from vagotomy on the right side below the point of emergence of the recurrent laryngeal nerve. More than 100 patients have been operated on in this manner. Unfortunately, the results of vagotomy have never been reported as fully as those of sympathectomy. In 1924, Kappis stated that a sufficient number of patients had then been operated on both by sympathectomy and by vagotomy on which as a basis the results of these interventions could well be estimated in three or four years. Although this period of time has elapsed, as far as we can find such a report has not been published from his clinic. However, from the scant figures available, vagotomy results successfully in many instances. We now have the unusual phenomenon that interruption of either of two nerve pathways that were originally supposed to have predominantly antagonistic motor effects on the lung produce the same result in the relief of asthma. When this discrepancy became evident many investigators attempted to explain it on the basis of a reflex arc, of which the sympathetic is the afferent limb and the vagus the efferent.

Patients in whom either vagotomy or sympathectomy has failed have been treated by subsequent intervention on the other system, or in the

case of the sympathetic system on the other side. Though occasionally the treatment is a brilliant success, the majority of reports show this group to have the most disappointing results. This is probably due to the fact that included in it are all those cases in which relief cannot be obtained by operations on the extrinsic nerves. On the other hand, there is a small group in which both systems have been interrupted primarily. If the effect of intervention is the relief of bronchospasm and if the latter has a bisystem control, then such a removal of the nerve pathways of both systems is more logical than the interruption of either one alone. Or, if the beneficial effect of operation lies in the breaking of a reflex arc which has complicated multiple afferent and efferent paths, then the interruption of both sensory and motor channels is more likely to reduce the stimuli getting back to the lung than are operations on only one system. In short, if interruption on either the sympathetic or the vagus nerve is sometimes curative, sometimes ineffective, but frequently partially beneficial, then it seems reasonable that to combine these procedures may result in greater improvement than is obtained from either one alone.

Basing his observations on the experimental studies of Braeucker, Kümmell, in 1926, reported the isolation and section of the posterior pulmonary rami in asthmatic patients. According to the experimental work in animals, it was believed that by this operation all extrinsic control of bronchiolar constriction in one lung from both systems and from both sides was removed. As far as we can determine, in only three cases mentioned in the literature has this operation been performed with apparently good immediate results, though their final status requires a later report. As Kümmell said, on a carefully constructed preparation of the vagus and sympathetic fibers, one can see how they combine into one individual complex. This is the point at which the separation must take place to effect a maximum area of nonconductance (fig. 2). In this manner, also, the nerve supply to no other organ is involved. This is a point which is probably of no great importance for any one intervention but which may well be significant if the several nerve paths that contribute to this plexus had to be divided separately. Under this heading, then, we consider two different groups. In the first of these, the combined intervention is carried out because of the previous failure of a simpler one, and the outlook is not promising. In the other group, both systems are interrupted primarily because this is thought to be a logical procedure and the probabilities of relief seem more promising.

In addition to the foregoing operations which have been carried out and to that proposed by Leriche and Fontaine which has been mentioned, Daniélopolu [87] proposed a most complicated procedure of ramisection. It was designed to interrupt the sympathetic communications passing to the lung through the stellate ganglion while this

structure was conserved. One has only to read the description of this procedure to realize that it will probably never be carried out.

Operations on the Chest Wall.—W. A. Freund [38] was the first to suggest an operation to increase mobilization in the emphysematous type of chest, variously described as the rigid or fixed thorax. This was accomplished by a unilateral chondrectomy of a varying number of the costal cartilages, thus making it possible for increased excursion.

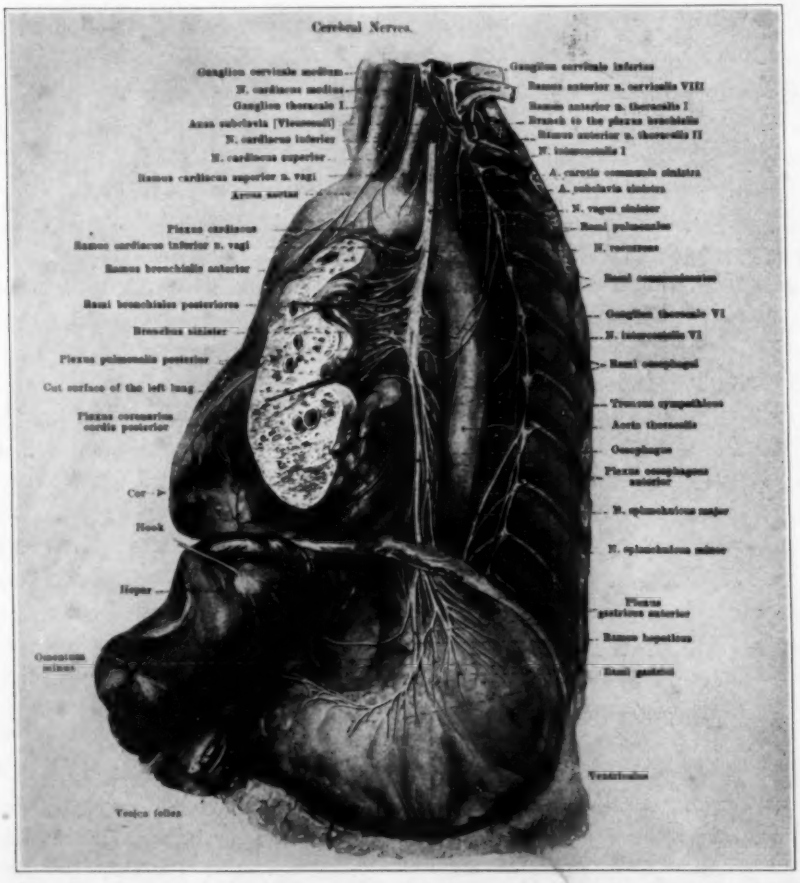

Fig. 2.—The extrinsic nerves to the left lung, showing the formation of the posterior pulmonary plexus, chiefly from branches arising from the main trunk of the vagus and joined by sympathetic fibers. From Spalteholz.

According to Bircher,[39] Freund's operation increases the vital capacity about 500 or 700 cc., on the average, while Heuer [40] referred to a maximal increase of 100 per cent. In one case, Bircher found chest expansion 10 cm. greater following unilateral excision of the second to the seventh cartilages. In 1918, he reported thirty cases of chondrectomy in which the patients had been under observation for several years, with the following results: cured (free from asthma and

bronchitis), 20 per cent; improved (lighter and less frequent attacks; able to work), 63 per cent; unimproved, 13 per cent; died, 3 per cent. Heuer assembled from the literature up to 1917 reports of about sixty cases in which Freund's operation had been carried out. Many of these showed recurrence of symptoms as fixation was reestablished. Although the patients were operated on by the old technic without destruction of the perichondrium, a few were still improved after three years. Failure, which occurred in the majority of these older patients and in some of Bircher's, was due to the reformation of the costal cartilages and consequent ankylosis at the point of resection. Several methods to prevent regeneration of cartilage were referred to by Bircher.[39] Seidel advised the implantation of a muscle flap from the pectoralis major; Hoffmann covered the ends of the rib with perichondrium; Axhausen destroyed the latter with the cautery, and Bircher himself advised painting with carbolic acid. Several authors have mentioned the removal of the perichondrium, but this seems to us a more difficult method than inhibiting regeneration by the proper chemical cauterization. The work of Head [41] on the prevention of rib regeneration by the use of Zenker's solution suggests its applicability in chondrectomy.

It seems paradoxic to suggest a posterior paravertebral thoracoplasty to increase the mobility of the hemithorax in the treatment of asthma and emphysema when the same operation is used to increase chest fixation in pulmonary tuberculosis. We will agree with Voelcker [42] that a columnar posterior paravertebral thoracoplasty will change the direction of the ribs from the transverse position characteristic of emphysema to the downward slanting position of a normal chest or even to an exaggeration of the latter. However, this change of the angle of the ribs is accomplished at the expense of diminished chest capacity and ultimate increased fixation of the side operated on. Herrmannsdorfer [34] described a resection of the left second costal cartilage with anterior mediastinotomy for bronchial asthma. We do not see how this procedure would benefit the condition. This surgeon reported another operation in which an exeresis of the third to the seventh intercostal nerves on one side was combined with corresponding resection of the ribs. Such a procedure, like the posterior paravertebral thoracoplasty, decreases the size of the chest and increases its fixation. Intercostalectomy was used by Warstat [43] in 1917 to diminish movement of the lung in the treatment of chronic pulmonary tuberculosis. Therefore, these three operations suggested by Voelcker and Herrmannsdorfer seem to us irrational when applied to the treatment of asthma. Hirschberg [44] devised an operation to increase respiratory movements by a transverse division of the sternum between the second and third costal cartilages. He claimed an increase in vital capacity of from 400 to 500 cc. Braun [46] reported a case of emphysema in which this pro-

cedure produced relief and in which the condition had recurred following the older method of chondrectomy. This operation does not appeal to us as a substitute for chondrectomy with destruction of the perichondrium.

Miscellaneous Operations.—Several years ago, operations on the nose and throat had a great vogue in the treatment for bronchial asthma. The removal of part of one turbinate or the correction of some other slight abnormality in this region were among the first therapeutic attacks in a new case. There is little doubt that any irritative or infectious focus in the upper respiratory tract should be eradicated. Possibly in this way some patients in whom the condition appeared to be true bronchial asthma have been relieved. However, the accumulated experience both of the internist and of the rhinolaryngologist has shown that the vast majority of asthmatic patients receive no permanent benefit from such procedures. Thus, Sluder [46] stated that removal of polyps, resection of the nasal septum and treatment of the anterior nasal cells has never influenced asthma in his cases. Sterling [47] carefully reviewed the relationship of asthma to operations on the nose and throat and reported an analysis of 300 personal cases studied from this point of view. In 36 per cent of them, corrective operations were performed on the nose and throat for troubles which the patients as well as their family physicians considered to be the cause of the asthmatic syndrome. Only three of these 115 patients were free from asthma for two years following such operative intervention. In the rest, there was no effect on the asthmatic paroxysms. Rowe [48] limited the indications for operations on the nose and throat to the removal of infections detrimental to the general health. The latter is obviously indicated, and possibly certain lesions which might play the rôle of an irritative focus should be removed. However, a special examination of the nose and throat with corrections of such abnormalities as are really indicated is a part of the thorough investigation and medical treatment of the asthmatic patients which must be carried out in all instances before any operative procedures on the extrinsic nerves is considered.

Operations on the thyroid gland are in the same category. Obviously, if any part of the respiratory tree is encroached on in such a way as to diminish its lumen, this difficulty should be corrected if possible before the case is considered one of bronchial asthma. Paroxysmal dyspnea in the presence of a goiter should not be considered as idiopathic bronchial asthma until the continuance of respiratory difficulty has been demonstrated to persist after the correction of the tracheal compression. Likewise, certain instances of improvement in so-called bronchial asthma following roentgen therapy seem to us probably due to its effect on enlarged tracheobronchial glands. Splenec-

tomy has been suggested for bronchial asthma by a Russian, Hynek,[49] in 1927. (This article was not available to us.) We have had no experience with this operation in asthma. Drey and Lossen [50] after accidentally discovering improvement of coexistent bronchial asthma following irradiation of the spleen for leukemia suggested a similar treatment for all asthmatic patients. A few optimistic results have been recorded by them and others. The history of therapy in asthma is replete with measures that have been used for a time, only to be found worthless later. This is well illustrated by Phillip [51] who in 1818 reported twenty or thirty cures by the simple application of the galvanic current. The excessive enthusiasm which was first aroused by nerve

TABLE 1.—*Operations*

I. Operations on the Extrinsic Nerves of the Lung
A. Sympathetic System
1. Unilateral cervical sympathectomy (Kümmell) (including more or less of the stellate ganglion)
2. Stellate ganglionectomy (Leriche)
3. Bilateral cervical sympathectomy
B. Vagus
1. Unilateral vagotomy (Kappis)
C. Combined Systems
1. Unilateral or bilateral sympathectomy plus unilateral vagotomy
2. Posterior pulmonary plexus resection (Kümmell)
D. Proposed Operations (not carried out as far as known)
1. Ramisection of the first four thoracic rami communcantes (Leriche)
2. Cervical sympathectomy, severing all fibers of vagus and superior laryngeal nerves entering the thorax, cutting rami communicates connecting the inferior cervical ganglion with the first thoracic nerve and with the sixth, seventh and eighth cervical nerves (Danielopolu)
II. Operations on the Wall of the Chest
1. Chondrectomy (Freund)
2. Posterior paravertebral thoracoplasty (Voelcker)
3. Anterior mediastinotomy (Herrmannsdorfer)
4. Exeresis of intercostal nerves 3 to 7, plus rib resection 3 to 7 (Herrmannsdorfer)
5. Transverse division of the sternum between the second and third cartilages (Hirschberg)
III. Miscellaneous Operations
1. Nose and throat, thyroid, etc.
2. Splenectomy

resection, for example, is no indication that it will ultimately have a definite place in the treatment of asthma. However, there seems to be little theoretically to recommend the possibility of preventing the asthmatic paroxysm by removal of the spleen. We feel that resection of the extrinsic nerves offers much more as an experimental operation than splenectomy or the removal of any other visceral organ.

Table 1 shows the more important operations suggested for the treatment of bronchial asthma. It is seen in going over this table that in grouping the cases a condensation into a simplified system is desirable. In fact, if each variation of operation on the sympathetic nervous system carried out by the individual operators was classified separately, the list of operations would be nearly as long as the list of operators. Consequently, we propose the simplified classification given in table 2

as a basis for studying the results of operative procedures in bronchial asthma.

ANALYSIS OF CASES RECORDED IN THE LITERATURE

Although the points described in the previous sections are of theoretical interest and frequently suggest rational therapy, the final test of any measure undertaken is the relief obtained from the asthmatic paroxysms. Does intervention on the extrinsic nerves offer any hope for those sufferers who have not been relieved by all of the usual medical methods, including particularly those of allergy? The results already obtained should be our guide in further efforts along this line. As recorded in the literature, in several hundred cases of bronchial asthma operations have already been performed on either the sympathetic or the parasympathetic system. Unfortunately, most of these have been inadequately reported. With the wave of enthusiasm that followed the pioneer work of Kümmell and Kappis in this field, many surgeons hastened to record a few cases without allowing an interval

TABLE 2.—*Basis for Studying Results of Operative Procedures in Bronchial Asthma*

1. Interruption of the sympathetic
2. Interruption of the vagus
3. Interruption of both sympathetic and vagus
A. Primary
B. Secondary (previous operative failures)
4. Restoration of respiratory excursion

sufficient to judge of the results. We feel that six months is the shortest period that makes the case worthy of any consideration in a statistical study. The majority of these cases followed this long are reported only in groups without details. This is a particularly unfortunate circumstance in bronchial asthma, because during this period many instances of dyspnea due to cardiac disease, to enlargement of the tracheal glands, or to other extraneous causes were undoubtedly included in the group in which operation was performed. A careful search of the literature, in fact, reveals only 29 detailed cases out of more than 300 patients operated on in which the results six months after operation are stated. We have assembled these in table 3.

It has seemed to us desirable to study the results collected from the literature in two different ways: (1) the assembly in a table of all cases reported in detail in which the result at least six months after operation is given; (2) the presentation of the statistics from the few clinics that have reported a considerable experience with these operations. As a matter of fact, it will be found that these two methods of analytical study lead to similar general conclusions. Each of them has certain points of advantage. The table of assorted cases has the obvious disadvantage that it is not a representative cross-section of the experi-

ence with these operations. In general, the successful case is much more apt to be reported than the unsuccessful one. On the other hand, it can be fairly contended that an operation so intricate in its technic as the total removal of the stellate ganglion, attempted by a large group of surgeons without particular experience along this line, will result in a high percentage of incomplete removals. Though both of these points are valid, still the case reports are of definite value and have the merit of being collected from a variety of sources. The chief objection to the second method is that the enthusiasm or prejudice of the particular clinic may color the expression of the results obtained. However, this method has the especial merit that it presents all of the results of a fairly extensive series and that it shows the disadvantages and complications as well as the advantages. The conclusions obtained from these two methods of study will be correlated. Only twenty-nine cases have been found acceptable for detailed analysis of results in bronchial asthma following operations on the vagus and the sympathetic nerves.

Table 4 is a résumé of the results in the individual cases included in table 3.

We may summarize, then, by stating that there are a few brilliant cures in extremely severe forms of asthma. Roughly, one half of the patients have been definitely improved, while frequently the other half, after temporary improvement, are in no better condition than before operation. The patients who were cured have been followed on the average almost two years. In some of these the condition may, of course, recur at a later date. However, when it is realized that in these patients the condition was, almost without exception, hopeless from the medical standpoint and that nothing was done to relieve the severe emphysema usually present, this is not altogether a discouraging outlook for the further trial of the operative method. Undoubtedly, a number of cases are excluded from the table on account of lack of the sufficiently long postoperative interval, in which the asthmatic attacks had already recurred. These are balanced, however, by a number of promising cases that had not been followed long enough to be included. Also, the occurrence of attacks for a short period after operation is compatible with ultimate relief as is shown in some of the cases cited. Furthermore, in a great many instances sympathectomy had been carried out on only one side. A number of examples are found in the table in which unilateral sympathectomy was followed by recurrence, while a similar procedure on the second side produced complete disappearance of the asthmatic paroxysms.

Turning from the disappointingly small number of cases reported in sufficient detail to permit individual study, we now review the results reported from individual clinics in which twenty or more operations

TABLE 3.—*Results of Extrinsic Nerve Operations in Individual Cases (From the Literature)*

Reporter	Year	Age	Sex	Clinical Data	Operation	Date	Result	Observation Interval	The Authors' Impression
1. Hesse..... (footnote 26)	1925	23	M	Asthma 15 years; roentgen therapy without relief; emphysema	Right cervical sympathectomy (total)	2/ 3/24	No attacks	19 mo.	Good result
2. Hesse.....	1925	24	M	Asthma 22 years; emphysema	Right total cervical sympathectomy	1/12/24	Complete relief Unimproved	8 mo. 19 mo.	Shows necessity of long follow-up
3. Hesse.....	1925	54	M	Asthma 13 years; rigid thorax; emphysema	Right cervical sympathectomy	4/ 2/24	Asthmatic attacks; no attacks (5 mo.)	9 mo. 14 mo.	Difficult to classify
4. Hesse.....	1925	40	F	Asthma 20 years; emphysema	Left cervical sympathectomy	6/21/24	No real attacks	15 mo.	Good result
5. Hesse.....	1926	30	F	Severe asthma 2 years; emphysema	Right sympathectomy	9/17/23	Recurrence	2 mo.	Failure after single and good result following double sympathectomy
					Left sympathectomy	3/ 8/24	No attacks	25 mo.	
6. Hesse	1926	24	M	Asthma 16 years; emphysema	Right sympathectomy	10/30/24	Recurrence	.....	Failure of unilateral sympathectomy; not improved by bilateral
					Left sympathectomy	11/15/24	Recurrence	11 mo.	
7. Hesse.....	1926	23	M	Asthma 3 years; emphysema; chronic bronchitis	Right sympathectomy	10/18/24	Unimproved	1 mo.	Failure of bilateral operation
					Left sympathectomy	11/28/24	Unimproved	11 mo.	
8. Hesse.....	1926	59	F	Asthma 13 years; emphysema; chronic bronchitis	Right sympathectomy	10/30/24	Unimproved	7 mo.	
9. Hesse.....	1926	46	M	Asthma 15 years; emphysema; chronic bronchitis	Left sympathectomy	12/10/24	Recurrence	2 mo.	Failure of bilateral operation
					Right sympathectomy	6/20/25	Unimproved	10 mo. after first operation	
10. Hesse.....	1926	17	M	Severe asthma 15 years; emphysema; chronic bronchitis	Left sympathectomy	12/10/24	Unimproved	.....	Failure of bilateral sympathectomy
					Right sympathectomy	1/17/25	Unimproved	11 mo.	
11. Hesse.....	1926	16	M	Asthma 12 years; chronic pneumonia	Left sympathectomy	12/23/24	No attacks Unimproved	5 mo. 12 mo.	Question of chronic lung suppuration
12. Hesse.....	1926	40	F	Severe asthma 7 years; continuous attacks 2 months	Right sympathectomy	3/ 5/25	No attacks Recurred	8 mo. 1 yr.	Value of long observation
13. Hesse.....	1926	47	F	Asthma 9 years; chronic bronchitis; emphysema	Right sympathectomy	4/19 25	Improved	7 mo.	

14. Hesse.....	1926	51	M	Asthma 38 years; chronic bronchitis; emphysema	Right sympathectomy	3/21/25	No attacks; nocturnal dyspnea	12 mo.	Suggests chondrectomy
15. Hesse.....	1926	40	M	Asthma 15 years; chronic fibrous pneumonia; chronic bronchitis	Right sympathectomy	4/11/25	Unimproved	12 mo.	Question of chronic lung suppuration
16. Hesse.....	1926	29	F	Severe asthma 2 years; chronic bronchitis; emphysema	Left sympathectomy	10/ 7/25	No attacks	6 mo.	
17. Leriche and Fontaine (footnote 35)	1926	45	F	Severe asthma 2 years; bedridden	Left stellate ganglionectomy	8/11/25	No attacks	36 mo.	Striking result
18. Leriche and Fontaine	1926	45	F	Asthma 6 years; exophthalmic goiter	Left stellate ganglionectomy	9/ 9/25	No attacks	30 mo.	Good result
19. Leriche and Fontaine	1927	51	M	Asthma 1 year; bronchitis; rigid thorax	Left stellate ganglionectomy	1/ 9/26	Unimproved	27 mo.	Suggests chondrectomy rather than nerve operation
20. Leriche and Fontaine	1927	58	M	Severe asthma; rigid thorax	Chondrectomy	1/ 5/27	Increased expansion; attacks persist	.....	Relief by combination of chondrectomy, stellate ganglionectomy and vagotomy
					Left stellate ganglionectomy	3/ 2/27	Unimproved		
					Right vagotomy	3/28/27	Free from attacks	10 mo.	
21. Kümmell, H., Jr..... (Beitr. z. klin. Chir. **132**: 249, 1924)	1924	57	F	Asthma 12 years; emphysema	Left sympathectomy	?	Recurrence within 5 months	.....	Follow-up too short
					Right sympathectomy	?	No attacks	9 mo. after first operation	
22. Rameriz and Pool.... (J. A. M. A. **84**: 2002 [June 27] 1925)	1925	39	F	Asthma 2 years; chronic bronchitis; emphysema; pulmonary fibrosis (x-ray)	Right superior sympathectomy	9/18/24	Unimproved	7 mo.	Incomplete operation; roentgenogram suggests intrapulmonary pathologic change
23. Rameriez and Pool...	1925	55	M	Asthma; chronic bronchitis; emphysema	Right cervical sympathectomy	6/12/24	Unimproved	10 mo.	
24. Harttung (Centralbl. f. Chir. **51**: 2300, 1924)	1924	37	M	Asthma 11 years	Left sympathectomy	10/23/	Good result	6 mo.	Complication paresis left upper extremity
25. Kroll (Deutsche med. Wchnschr. **53**: 1328, 1927; Centralbl. f. Chir. **54**: 1885, 1927)	1927	?	?	Asthma 2 years	Left sympathectomy	2/24/	Improved	30 mo.	
26. Lutz (Centralbl. f. Chir. **54**: 1883, 1927)	1927	31	?	Asthma since infancy	Left sympathectomy	1/27/	No attacks	7 mo.	
27. Lutz.....	1927	57	?	Severe asthma for several decades	Total sympathectomy	?	Recurrence	6 mo.	
28. Böttner (Med. Klin. **21**: 197, 1925)	1925	57	M	Asthma 50 years; roentgen therapy without help	Left sympathectomy and partial vagotomy	2/24/	Unimproved	12 mo.	
29. Göbell..... (footnote 52)	1928	?	?	Severe asthma	Double sympathectomy	12/ 6/23	No attacks	52 mo.	

for bronchial asthma are recorded. Probably this gives us a more accurate conception of what can be expected from intervention on the extrinsic nerves. There are four rather extensive series in which nearly all of the patients have been followed for more than a year, and in some the earliest operations were performed five years previous to the report. Göbell,[52] who had presented the most extensive series, had intended to wait until five years had elapsed since operation in his cases, but at the request of Lengemann summarized his results in June, 1928, in a symposium before the Association of Northwest German Surgeons. Although he had operated on 112 patients, he reported the results in only 98 of these. Consequently, though we do not know the average length of time the patients have been followed, it is seen that for a number of them the period of observation has been more than four years and that the ones operated on most recently have been excluded from consideration. Lengemann's [53] series, pre-

TABLE 4.—*Résumé of Results in Cases Included in Table 3*

Total Cases, 29		
Cure 8 cases, or 28 per cent	Improved 5 cases, or 17 per cent	Unimproved 16 cases, or 55 per cent
Observed an average of 24 months	Observed an average of 15 months	Observed an average of 11 months
2 cases.....3 years or over	1 case.....2 years or over	7 cases.....1 year or over
2 cases.....2 years or over	1 case.....1 year or over	9 cases.....6 months or over
2 cases.....1 year or over	3 cases.....6 months or over	
2 cases.....6 months or over		

sented at the same meeting, is of particular merit in regard to the length of time elapsed since operation. He brought out the comparison between his results published in 1925 and those in the same cases two and a half years later. These two series furnish a fairly accurate history of patients who have undergone such operations. It is particularly disappointing that the two originators of the principal operations on the nerves, Kümmell and Kappis, have not seen fit as yet to give a careful statistical study of their results. Kümmell,[54] in the aforementioned symposium, made an impassioned appeal in favor of operation on the nerves. However, he contented himself with an elusive statement in regard to his results, to the effect that he had about 40 per cent cures and that a total of about 70 per cent of the patients operated on were improved. He made no statement as to the interval of observation. In 1924, Kappis [36] stated: "Of our patients operated with vagus division the large part after operation are freed from asthma . . . and only a few have not been improved." At that time, he stated that a sufficient number of patients had been operated on by sympathetic and vagus division to determine the value of these procedures by studying the

results after two or three years. In spite of a careful search, we have been unable to find any subsequent report on this subject from his clinic. In his discussion, Kümmell upbraided Kappis along with Fründ, Lengemann and others for expressing themselves less enthusiastically than three or four years previously. This is the only suggestion of a recent opinion by Kappis that we have found. If we had available a careful study of the results of Kümmell's and Kappis' operations

TABLE 5.—*Series Reported from Individual Clinics*

Reporter	Date	Total Cases	Total Operations	Operation	Number	Cured, per Cent	Improved, per Cent	Unimproved, per Cent	Unknown, per Cent	Mortality, per Cent	Interval
Göbell..... (footnote 52)	1928	98	105	Single sympathectomy	7	0	..	100	..	..	Uncertain; earliest operation 4½ years ago
				Double sympathectomy	19	42	11	42	5		
				Right vagotomy	1	0	..	100			
				One side sympathectomy plus vagotomy	16	50	..	19	31		
				Double sympathectomy with vagotomy	61	43	18	23	14	2	
				Total (by cases)	98	43	13	29	14	1	
Hesse..... (footnote 26)	1926	18	23	Unilateral sympathectomy, bilateral sympathectomy	18	28	17	56	..	..	Usually a year or so
Kaess..... (footnote 24)	1925	28	28	Unilateral sympathectomy	28	29	29	43	..	..	Over 6 months
Fründ..... (footnote 23)	1928	48	55	Sympathectomy	1	..	..	100	..	..	Not given; earliest case at least 3 years of age
				Vagotomy	47	13	21	66			
				Vagotomy and sympathectomy	7	..	..	100			
				Total (by cases)	48	12	21	67			
Lengemann (footnote 53)	1925	27	44	Unilateral sympathectomy	10	20	30	50	..	..	At least several months
				Bilateral sympathectomy	2	50	50				
				Vagotomy	3	33	..	66			
				Combined	12	33	33	25	..	8	
				Total (by cases)	27	33	26	37	..	4	
	1928	20	25	Unilateral sympathectomy	11	18	..	82	..	..	Over 2½ years
				Vagotomy	2	..	..	100			
				Bilateral sympathectomy	2	50	..	50			
				Combined	10	10	20	70			
				Total (by cases)	20	15	15	70			
				Total five series	211	30	18	45	7	1	

during the years 1923 and 1924, our task of evaluating the procedures would be easier. The series recorded in table 5 give the results in 211 cases after a moderately long interval. While there is a variation from series to series in the exact proportion of (1) those who are symptom-free, (2) those who are improved, and (3) those who are unimproved, there is a surprising correspondence between the figures so obtained and those which we found by analysis in the cases reported in detail. Thus, of the 211 patients, 30 per cent are reported as cured; 18 per cent as improved; 45 per cent as unimproved and 7 per cent as unknown, with 1 per cent mortality. In no individual series is the

percentage of improved patients below 30 per cent. Summarizing the results reported in the literature, one finds that a few of the patients have had remarkable relief from a most serious asthmatic condition. About one third of the patients are completely relieved for the period of observation varying from six months to five years. Including these, about half of the patients have been definitely improved while half have been unimproved.

In selecting the cases for analysis, we have investigated all reported instances of such operations that we could find. We excluded a large number as unsatisfactory chiefly because a sufficient period of postoperative observation was not stated. In a few instances, we did not have access to the original articles (chiefly Russian). Leder [56] and Orth [57] mentioned the report of some other cases apparently given before local medical societies which were not included in the indexes of medical literature. The latter are included after the authors' names. The following is the list of these cases excluded from our statistical analysis.

Bottner, two additional cases, Med. Klin. **21**:197, 1924.
Brschosówki, three cases, Nowy Chirurg. Arch., 1925, no. 81.
Erkes, one case, Centralbl. f. Chir. **53**:718, 1926.
Ewojan, nine cases, no reference; quoted by Orth.
Fisban, one case, no reference; quoted by Leder.
Flocken, four cases, Arch. f. klin. Chir. **130**:68, 1924.
Fründ, one case, Beitr. z. klin. Chir. **136**:58, 1926.
Von Genersich, one case, Klin. Wchnschr. **3**:2011, 1924.
Grekow, six cases, Cong. russe de chir., 1925, quoted by Leder.
Heile, one case, Centralbl. f. Chir. **51**:862, 1924.
Hesse, two additional cases, Beitr. f. klin. Chir. **136**:429, 1926.
Ischiyama, two cases, Japan M. World **5**:289, 1925.
Jenckel, three cases, Centralbl. f. Chir. **51**:897, 1924.
Jungmann and Brüning, three cases, Klin. Wchnschr. **3**:399, 1924.
Kappis, five cases, Med. Klin. **20**:1347, 1924.
Karditz, one case, no reference; quoted by Orth.
Kern, one case, Surg. Gynec. Obst. **42**:28, 1926.
Kroll, three additional cases, Deutsche med. Wchnschr. **53**:1328, 1927.
Kümmell, three cases, Klin. Wchnschr. **2**:1825, 1923.
Kümmell, Jr., eight additional cases, Beitr. z. klin. Chir. **132**:249, 1924.
Lawen, one case, Arztl. Vereign z. Marburg, Feb. 21, 1924; quoted by Leder
Leriche and Fontaine, one additional case, Bull. et mém. nat. de chir. **54**:600, 1928.
Lewit, six cases, Cong. russe de chir., 1925, quoted by Leder.
Mandelbaum, eight cases, no references; quoted by Orth.
Mirizzi, one case, Semana med. **1**:930, 1925.
Mravanadre, five cases, no reference; quoted by Orth.
Orth, two cases, Vereinsbl. d. pfalz Aerzte **5**:318, 1928.
Osoliy, two cases, no reference; quoted by Orth.
Neuber, one case, no reference; quoted by Leder.
Radice, three cases, Ann. ital. di chir. **3**:9, 1924.

Rehbein, one case, München. med. Wchnschr. **72**:1885, 1925.
Rhode, one case, Arch. f. klin. Chir. **139**:669, 1926.
Ringel, six cases, Cong. allemand de chir., 1924; quoted by Leder.
Popke, three cases, Arch. f. klin. Chir. **133**:148, 1924.
Rothfuchs, three cases, Centralbl. f. Chir. **51**:903, 1924.
Sauerbruch, two cases, Arch. f. klin. Chir. **133**:277, 1924.
Schulze, two cases, no reference; quoted by Orth.
Silberger, two cases, no reference; quoted by Orth.
Svjatuchin, two cases, no reference; quoted by Orth.
Winterwitz, one case, no reference; quoted by Leder.

Witzel,[28] in a footnote in 1925, spoke of forty cases but did not give details.

Brüning [33] mentioned twenty-six cases without details in the discussion of Kroll's report before the Berlin Surgical Society in 1927.

Kappis [36] spoke of vagotomy performed on a great many patients but has never even published the total number or given any detailed report of the results.

In regard to the operation of choice, it seems to us that the statistical evidence is still too scanty for one to arrive at any final opinion. The patients in whom vagotomy alone was performed make the poorest showing of any large group. In fifty cases, 23 per cent have shown improvement. Without Kappis' results, it is difficult to decide on the value of this procedure. When used alone it seems to be less satisfactory than when combined with intervention on the sympathetic or than when the latter alone is done. The most favorable results reported in any extensive group are those of Göbell.[52] Curiously enough, the percentages of his symptom-free cases are practically the same (from 42 to 50) following (1) double sympathectomy, (2) unilateral sympathectomy plus vagotomy and (3) double sympathectomy plus vagotomy. Göbell concluded that unilateral sympathectomy is not followed by any lasting success. This certainly seems erroneous as some of the most brilliant results have followed unilateral sympathectomy; for example, three patients of Kümmell's [55] who in 1927 had been symptom-free for three years and the two in Leriche and Fontaine's [35] 1928 report, relieved for two and a half and three years, respectively.

It is evident from studying some of the cases reported that a short interval of time is worthless as an index of the ultimate result. Frequently, a patient will improve for several weeks or months only to have a relapse. Case 12 from table 3 illustrates the fallacy of accepting as short a period of time as three months, as did Leder [56] in determining the result of operation. We have arbitrarily chosen six months as the minimum interval making the case worthy of study. In this analysis, we have stated as accurately as possible the interval following operation. Any one who chooses a longer interval for estimating results may do so from these statistics. We believe three years

at least should be the period of freedom following operation before we may speak of a cure of bronchial asthma. However, if at this time we took such a period there would be few cases available for analysis, though it is certain that several patients with bronchial asthma have been relieved for more than four years. A comparison of the two series of Lengemann [53] illustrates the danger of assuming a cure after a few months. But this equally demonstrates that even after another interval of more than two and a half years, 30 per cent of the patients still show improvement. Brüning's [33] position seems to us too conservative. As a matter of fact, his results as given in the discussion of Kroll's paper in 1927 correspond well with those obtained by other operators. At that time he stated that he would regard one third of his results as final cures if he had not seen relapses occur in many cases after a greater interval. It is possible that a relapse will occur in an occasional case after two or three years of freedom from symptoms, but we feel that this must be unusual.

REPORT OF CASE

Our interest in extrinsic nerve intervention in bronchial asthma was stimulated by the reports of Kümmell.[20] The case which we report here immediately suggested itself to us as a suitable one for attempted surgical relief. As the record shows, the patient had suffered from severe asthma for a number of years and was unrelieved by all of the usual types of medical treatment. He was found sensitive to more than fifty different proteins, and antiallergic measures were also unsuccessful. He was unable to work and spent long periods in the hospital. The fact that surgical intervention in the treatment of asthma was still in the experimental stage was explained to him, and after careful consideration he came to us asking for the operation.

We chose resection of the posterior pulmonary rami as the most logical operation. Section at this point interrupts the fibers controlling the finer air passages from both the vagus and the sympathetic including those crossing from the opposite side.

History.—W. T., a clothing cutter, aged 36, was admitted to the Rochester General Hospital on Aug. 23, 1928. The family and past histories were entirely negative for asthma or other allergic manifestations. He began having asthma in June, 1918, while serving in the United States Army at Kelly Field, Texas. Following a period of about seven weeks' hospitalization, he was discharged from the army for physical disability because of his asthma. Since that time, he has not been free from attacks for more than a week. The frequency and severity have progressively increased. About three years before admission, he had to stop work on account of them. He complained of shortness of breath at all times, worse when lying down. He was subject to frequent smothering spells and many nights sat up in a chair for hours at a time because of shortness of breath. He did not consider this severe enough to call it an attack of asthma. He had a chronic

productive cough with expectoration varying in amount from one half to two sputum cups daily. The sputum was bluish-gray, thick and nonodorous and had never contained blood. He frequently had had severe pain across the center of his chest, lasting three or four hours at a time, aggravated by cough or deep breathing. During an asthmatic paroxysm, he was conscious of a rapid heart action and had frequent sharp precordial pains. The weight had decreased from 195 to 156 pounds (88.5 to 70.8 Kg.). During the past five years he had been a regular attendant of the asthma clinic of the Rochester General Hospital and had been a patient in the wards of the hospital on numerous occasions, sometimes remaining as long as five months. His case was also studied at the Brooklyn Naval Hospital and at the United States Veterans' Bureau Diagnostic Center in Washington. In spite of all therapy the attacks of asthma increased in severity and frequency, and it became more and more difficult to secure relief by drugs during an attack. On Feb. 9, 1926, a tonsillectomy was performed. The removal of the tonsils had no effect on the asthma.

The severity of the asthmatic attacks and the seriousness of the disability can best be described by quoting a few abstracts from the hospital record of previous admissions. During a hospitalization period from Jan. 12, 1926, to June 17, 1926, it was necessary to use eighty-five doses of morphine (¼ grain [16 mg.]) and 454 doses of codeine (1 grain [0.6 Gm.]) in addition to large amounts of epinephrine.

April 14, 1926: "For the last two days has been almost continuously in attacks, relieved only for a short time by epinephrine. Is getting large quantities of morphine and epinephrine with little relief. Ankles markedly edematous. Is a very sick man." "Since leaving the hospital on Dec. 1, 1926, has been improved but has had three or four attacks a week. Without epinephrine attacks last several hours or may run for a week at a time with eight to ten peaks of severity during the course of a day."

March 3, 1927: "Has been having a terrible time with asthma. Had nearly 100 minims (6.1 cc.) of epinephrine last night."

April 21, 1927: "For the past one and a half months has had practically constant asthma, day and night, always worse at night. Coughing and expectorating a great deal."

Nov. 12, 1927: The patient was admitted to the hospital suffering from a severe attack of asthma. Medication the first night was as follows: 7:45 p. m., 15 minims (0.9 cc.) of epinephrine; 9:15, 15 minims of epinephrine; 12 o'clock, ¼ grain morphine; 12:25, 15 minims of epinephrine; 12:27 1/100 grain (0.6 mg.) of scopolamine and 1/100 grain glyceryl trinitrate; 12:30, amyl nitrite; 2:15, menthol inhalations. "Following this, patient slept until 5 a. m. when more epinephrine was necessary."

July, 1928: "Attacks very poorly controlled by epinephrine. Scopolamine more efficacious."

Physical Examination.—The patient weighed 70.8 Kg. (156 pounds) and was 181.5 cm. (5 feet 11½ inches) tall. The nose was normal. The tonsils had been removed. The fossae were clean. The thyroid showed no enlargement; the lateral lobes were barely palpable. The chest showed a drooping posture; the shoulders were rounded; the anteroposterior diameter was increased; the clavicles were raised anteriorly and were equally prominent. There was fair respiratory excursion, equal on the two sides. The percussion note was hyperresonant. Expiration was prolonged. Constant sonorous and sibilant râles were heard scattered throughout both lungs. The heart was not enlarged. The sounds were clear. There were no murmurs. The pulse rate was 78 when the patient was recumbent;

88 when he was sitting, and 88 when he was standing. The pulse was regular in rate and rhythm. The blood pressure was 116 systolic; 77 diastolic. The radial arteries were not sclerotic.

Laboratory Examinations.—Urinalysis was repeatedly negative. The blood showed white cells, 7,000; hemoglobin, 82 per cent; red blood cells, 4,464,000; differential polymorphonuclear neutrophils, 65 per cent; polymorphonuclear eosinophils, 8 per cent; lymphocytes, 32 per cent. The Wassermann reaction of the blood was repeatedly negative.

The blood chemical determination showed: nonprotein nitrogen, 35 mg. per hundred cubic centimeters; chlorides (whole blood), 510 mg. per hundred cubic centimeters; sugar, 120 mg. per hundred cubic centimeters. The sputum was repeatedly negative for tubercle bacilli. The electrocardiographic report showed a negative tracing. The vital capacity was 4,850 cc. (a 26 per cent increase over the normal for the patient's weight and height).

TABLE 6.—*Positive Reactions to Skin Tests*

Vegetables	**Fruits**	**Epidermal Products**
Asparagus	Peach	Chicken feathers
String beans	Apple	Goose feathers
Kidney beans	Grapefruit	Dog, hair and dander
Lima beans	Lemon	Horse, hair and dander
Navy beans	Orange	Rabbit, hair and dander
Irish potato	Watermelon	Cat, hair and dander
Sweet potato	Cantaloupe	Cow, hair and dander
Peas		
Beet		
Carrot	**Grains**	**Beverages**
Parsnips	Rye	Coffee
Turnip	Wheat leucosin	Tea
Cabbage	Barley	Cocoa
Celery	Buckwheat	
Lettuce	Corn	
Onion	Oats	**Condiment**
Spinach	Rice	Black pepper
Egg plant		Ginger
Pumpkin		Mustard
Squash	**Meats**	Paprika
Cucumber	Beef	Vanilla
Tomato	Pork	
Radish	Mutton	
Swiss chard	Horse	**Special**
Mushroom	Goat	Orris root
Okra		Streptococcus (autogenous sputum)

Roentgen examination of the paranasal sinuses revealed some haziness of the right antrum. (It was later punctured and found normal.) Repeated examination of the chest on several admissions showed slight peribronchial infiltration but no evidence of tuberculosis. Roentgenograms of the chest taken during a severe asthmatic paroxysm revealed no essential difference from those taken during the interval between attacks.

The positive reactions to the skin tests for protein hypersensitivity are shown in table 6.

During the long period of observation of this patient, there was complete agreement that he was suffering from severe bronchial asthma. Skin tests demonstrated that he was sensitive to a large number of proteins. Although every possible precaution was taken to prevent his contact with these substances, there was no improvement in his condition. In the hope that his was a bacterial allergy, treatment was attempted by a vaccine made from streptococcus found in his sputum. This therapy gave negative results. The list of drugs used in the treatment of asthma was exhausted without benefit except for the alleviation of an asthmatic attack, and it was becoming increasingly difficult to secure relief

during a paroxysm. The patient stated that life was unbearable under these conditions. When he consulted us, all of the established medical measures had failed to stop the progression of the asthma. Consequently, we did not hesitate to suggest an operation still in its experimental stage.

Operation.—On Aug. 28, 1928, with the patient under gas-oxygen and novocaine hydrochloride anesthesia, we opened the right side of the chest widely under positive pressure obtained with the usual gas anesthesia apparatus. The scapula was mobilized by an incision encircling its angle. The fifth rib was resected from the transverse process to the anterior axillary line. The pleural incision was made through the bed of the fifth rib. The fourth rib was transected to increase the exposure. The lung was quite diffusely adherent to the parietal pleura but was easily separated by sharp dissection. When the lung was held forward, the right lateral wall of the mediastinum was easily reached. Our posterior incision gave excellent exposure. The azygos vein was taken as landmark. The vagus nerve was exposed by an incision through the mediastinal pleura above the vein. Novocaine hydrochoride was injected into the nerve. It was picked up on a hook and by the exertion of a little traction its location below the azygos vein was identified. Another incision was made through the pleura just below the vein, and the vagus was dissected downward, exposing four main branches running to the posterior surface of the bronchi (fig. 3). After these branches were dissected out to the parenchyma of the lung, they were cut. The main trunk of the vagus was entirely freed, insuring section of all the smaller branches. The vagus was cut at the inferior border of the right main bronchus, for fear there might be lower branches that had not been exposed. (We feel that section of the vagus trunk was an unnecessary step, and plan to omit it in the future.) Sympathetic fibers were not identified during the operation, but from our dissections and the observations of Braeucker we are sure that most of those going to the posterior pulmonary plexus were destroyed. The lung was made to expand fully and the chest wound closed in layers in the usual manner. The patient stood the operation well. Convalescence was delayed by a moderate sized hemopneumothorax which was gradually absorbed following aspiration.

Follow-Up Study Eight Months After Operation.—The patient was entirely free of asthmatic attacks for a period of three months following intervention. On Nov. 27, 1928, after spending several hours at an indoor circus he began to have some dyspnea. The patient is hypersensitive to horse dander. As there were many horses in the performance, it is probable that he received an overwhelming dose of this allergen. He was admitted to the hospital that evening with a typical attack of asthma. The medical resident noted that this attack was much milder than previous attacks in which he had seen him. Since that time he frequently has attacks of mild dyspnea, particularly at night, but the respiratory difficulty is not comparable to the severe asthmatic paroxysms that he had prior to operation. These attacks are controlled by a single dose of epinephrine, whereas previously he frequently required repeated doses, sometimes as much as 100 minims, in the course of a night. Narcotics are no longer required. He has complained of pain along the course of the incision and a feeling of tightness in the right side of the chest. He stated to one of the medical consultants that since his operation the attacks of asthma have been infinitely milder. Without our knowledge, he urged another patient with a severe form of asthma to have this operation performed.

SUGGESTIONS FOR FURTHER INVESTIGATION

The bronchostenosis producing the asthmatic attack being a bilateral reaction, the question naturally is raised as to how unilateral section of the extrinsic nerves can modify the paroxysm sufficiently to produce relief. The hypothesis advocated by several that the tonus in a supposed bronchoconstrictor center is diminished by the removal of unilateral afferent impulses does not impress us. The only explanation that is satisfactory to us has to do with vital capacity and air requirement.

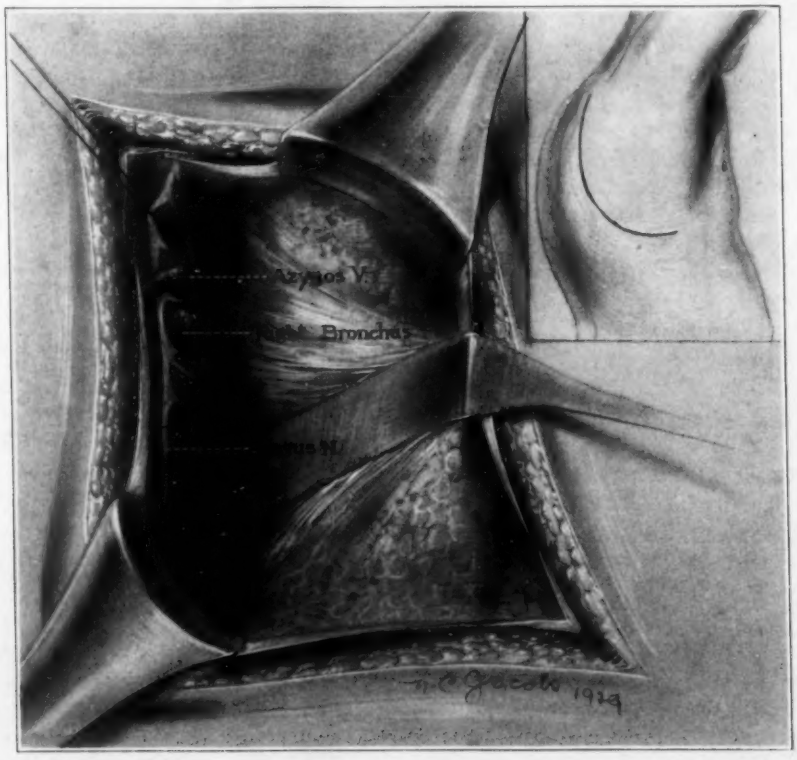

Fig. 3.—The operative exposure of the posterior pulmonary plexus through a posterior, transpleural incision.

Normal vital capacity is so much in excess of the tidal air that respiration can be carried on by one lung if its air interchange is free.

This conception affords a satisfactory explanation of the failures to relieve asthma. The continuation of a restricted air interchange on the side operated on may be due to: (1) an incomplete removal of the extrinsic nerve fibers to the lung (operation incomplete in plan or in technic) or (2) an uninfluenced thoracic cause (control by intrinsic nervous mechanism or rigid thorax). If the cause of a failure is the latter, no operation on the extrinsic nerves will avail. Intrathoracic

interruption of both vagus and sympathetic pathways to the lung is most likely to avoid the danger of the former cause. (In Kümmell's [20] two cases of posterior pulmonary plexus resection in which relief resulted, cervical sympathectomies had previously failed.)

We have briefly referred to roentgen therapy under the discussion of splenectomy. A few observers have published enthusiastic reports of this method of treatment (Schilling,[58] Gerber [59] and Klewitz [60]). Freund [23] combined intervention on the extrinsic nerves with roentgen-treatment. At first, in 1926, he used the latter only in cases in which operation failed to relieve the condition. More reecntly, in 1928, he reported good results from roentgen therapy alone (70 per cent improvement). He advocated the trial of roentgen treatment before the consideration of operation. We feel that this position is sound if the therapy is not followed by unfortunate sequelae. Heavy dosage of deep roentgen therapy has sometimes caused fibrosis of the lung. It remains to be seen how much asthmatic patients can be benefited by roentgen treatment that is confined within this limit of safety. As Kümmell emphasized, whatever its value it is not to be considered ultimately as a competitor with extrinsic nerve operations because the latter are to be undertaken only after the failure of all conservative measures.

Entirely too little attention has been paid to the treatment of the fixed chest. It is universally recognized that emphysema and its accompanying chronic bronchitis are frequent complications of asthma. Most of the authors whose cases we reviewed stressed the presence of these conditions. Several of them went so far as to remark that the complete relief of dyspnea could not be expected on account of these complications even though the element of bronchostenosis should be entirely overcome by operation on the nerve. However, few undertook to correct the fixation of the chest. Many of these patients would probably have been greatly benefited by chondrectomy, and some of them relieved without operation on the nerve. (Compare Leriche's [36] fifth case, in which relief was obtained by chondrectomy plus sympathectomy plus vagotomy and in which the patient himself thought the chondrectomy was more beneficial than the operation on the nerves). In his experience, Ischiyama [61] found mobilization of the wall of the chest of more value than cervical sympathectomy. We have discussed the various types of operations to overcome the fixation of the chest in the section headed "Operations for Bronchial Asthma." Chondrectomy (Freund) with destruction of the perichondrium has an excellent record of achievement. There is no other operation at present that seems to us as satisfactory for this purpose.

Bronchial asthma has been considered by many to be of psychogenic origin. The discovery of the allergic basis as a cause in many instances, at least, is definite proof of an underlying pathologic process. The

cure in isolated cases by simple measures involving the removal of a specific allergen from the patient's environment (such as chicken feathers or horse dander) would have been taken a few years ago as proof of the psychogenic basis for asthma. As the knowledge of this subject increases, one finds the explanation for more and more cases of asthma. Thus, there are separate groups susceptible to pollens, animal emanations, dietary constituents, bacterial proteins absorbed from infectious focci, etc. If asthma is a pure neurosis, the results of all operative procedures should be identical. However, we have seen that after operations on the nose and throat practically no lasting improvement of the asthma follows, while operations on the extrinsic nerves of the lung have given a fair percentage of completely relieved patients. There is a psychogenic factor in all diseases, and from this the asthmatic patient is not immune. Probably it is greater in such patients than it is in cases of ruptured duodenal ulcer, but this factor does not completely explain the pathogenesis in one any more than in the other.

Pathologic changes in the sympathetic ganglions removed at operation from asthmatic patients have been described in the literature, consisting of degeneration, fatty changes, scarring, chronic inflammatory reaction, etc. However, these are not specific for asthma. A correlation of any gross or histologic nerve lesion with a definite clinical syndrome would be of much interest but has not yet been achieved. This subject deserves further pathologic study.

Some method of choosing in advance those patients who will be benefited by operations on the nerves would be extremely valuable. Rehbein [62] spoke of tenderness over certain cervical sympathetic ganglions and asserted that the removal of the latter alone is followed by the relief of asthma. It seems to us extremely unlikely that this point will prove to be an important aid in the selection of cases. The temporary interruption of nerve paths may be a much more useful test. Rehbein noted at operation that in the successful cases local infiltration with procaine hydrochloride caused freer breathing and subjective improvement even before the incision was made. Dramatic relief of extreme dyspnea at the moment that the vagus nerve was anesthetized was obtained in the fifth case of Leriche and Fontaine.[36] They, as well as several others, have suggested a preliminary blocking of the autonomic nerves during an asthmatic attack. If this affords the patient relief, they advise operative intervention on the nervous system. This seems like a reasonable test, and it should be given careful trial. It appears to us less likely that it will assist those who interrupt only one system to decide between vagus section and sympathectomy.

CONCLUSIONS

1. Although our knowledge of the mechanism involved in producing the asthmatic attack is most incomplete, the hypothesis that the extrinsic nerve supply of the lung plays a significant rôle in it is the basis of operative interventions on the autonomic nervous system.

2. Anatomicophysiologic studies indicate that there is a bilateral, bisystem nervous control of the size of the lumen in the finer air passages.

3. More than 300 operations on the autonomic nervous system in the treatment of bronchial asthma have been reported. Many of these are inconclusive for lack of sufficient data. An analysis of the carefully followed and reported cases showed that: (*a*) in about one-half, the operations have been complete failures; (*b*) in the others, varying degrees of improvement have been obtained, and (*c*) there have been a few brilliant cures in apparently hopeless cases.

4. Successful results have followed interruption of the vagus alone as well as of the sympathetic system alone. When operation on one system has failed, the interruption of the other is less commonly successful. However, the initial severing of both systems at the posterior pulmonary plexus seems to us the most logical intervention. An insufficient number of patients have been operated on in this manner to determine its comparative value. We report one case in which benefit was obtained over a period of eight months by this procedure.

5. Intervention on the autonomic nervous system for asthma should be considered as being in the experimental stage. However, if no contraindications are present, the results empirically obtained in this manner justify the attempt to relieve severe paroxysmal asthma when conservative measures, especially antiallergic methods, have without avail exhausted their possibilities.

6. Many asthmatic patients have a sufficient degree of emphysema and fixation of the thorax greatly to limit the respiratory exchange. In such cases, if the cardiac function is not already too greatly impaired, a mobilizing operation should be performed on the thoracic wall. This procedure alone may afford great relief from the asthma and should at least precede any operation on the autonomic nervous system in such instances.

BIBLIOGRAPHY

1. Alexander, H. L.: Bronchial Asthma: Its Diagnosis and Treatment, Philadelphia, Lea & Febiger, 1928, p. 171.

2. Braeucker, W.: Die experimentelle Erzeugung des bronchial Asthmas und seine operative Beseitigung (Anatomisch-Chirurgische Studie), Arch. f. klin. Chir. **137**:463, 1925; **139**:1, 1926; Die Lungennerven und ihre chirurgische Bedeutung, ibid. **142**:38, 1926; Der Brustteil des vegatativen Nervensystems und seine klinischchirurgische Bedeutung, Beitr. z. klin. d. Tuberk. **66**:1, 1927.

3. Helmont, J. B., quoted by Alexander (footnote 1).

4. Reissiesen, F. D.: Ueber den Bau der Lungen, Berlin, 1822.

5. Wedemeyer, G. L. H. C.: Untersuchungen über den Kreislauf des Blutes und insbesondere über die Bewegung desselben in den Arterien und Capillargefässen, mit erklärenden Hindeutungen auf pathologische Erscheinungen, Hanover, 1828.

6. Williams, C. J. B.: The Pathology and Diagnosis of Diseases of the Chest (With an Appendix Containing Various Opinions and Experiments on the Motions and Sounds of the Heart and on the Bronchi), ed. 4, London, 1840.

7. Huber, H. L., and Koessler, K. K.: The Pathology of Bronchial Asthma, Arch. Int. Med. **30**:689 (Dec.) 1922.

8. Strümpell, A.: Zur Pathologie und Behandlung des Asthma bronchiale, Med. Klin. **4**:6, 1908.

9. Beau, J. H. S.: Recherches cliniques sur l'anesthésia, suivies de quelques considérations physiologiques sur la sensibilité, Arch. gén. de méd. **16**:1, 1848.

10. Blackley, C. H.: Hay Fever: Its Causes, Treatment and Effective Prevention: Experimental Researches, London, 1880.

11. Solis-Cohen, S.: The Use of Adrenal Substance in the Treatment of Asthma, J. A. M. A. **34**:1164 (May 12) 1900.

12. Coca, A. F.: Relation of Atopic Hypersensitiveness (Hay-Fever, Asthma) to Anaphylaxis, Arch. Path. **1**:96 (Jan.) 1926.

13. Yankauer, S.: Recent Progress in Knowledge and Treatment of Diseases of the Upper Respiratory Tract: Larynx, Trachea and Bronchi, Laryngoscope **20**:788, 1910.

14. Ephriam, A.: Ueber die Wirkung des Adrenalins beim Asthma bronchiale und bei der chronischen Bronchitis, Deutsche med. Wchnschr. **38**:1453, 1912.

15. Curschmann, H.: Ueber Bronchiolitis exudativa und ihr Verhältniss zum Asthma nervosum, Deutsches Arch. f. klin. Med. **32**:1, 1883.

16. Longet, M., 1842, quoted by Alexander (footnote 1).

17. Dixon, W. E., and Brodie, T. G.: Contributions to the Physiology of the Lungs: I. The Bronchial Muscles—Their Innervation and the Action of Drugs Upon Them, J. Physiol. **29**:97, 1903.

18. Weber, E.: Neue Untersuchungen über experimentelles Asthma und die Innervation der Bronchialmuskeln, Arch. f. Physiol., 1914, p. 63.

19. Braeucker, W., and Kümmell, H., Jr.: Ueber die "reine" Vaguswirkungen an den Bronchien, Arch. f. d. ges. Physiol. **218**:301, 1927.

20. Kümmell, H., Sr.: Die operative Heilung des Asthma bronchiale, Klin. Wchnschr. **2**:1825, 1923; Zur chirurgischen Behandlung des Asthma bronchiale, Arch. f. klin. Chir. **127**:716, 1923; Die Ursachen des Asthma bronchiale und seine operative Behandlung, ibid. **133**:593, 1924; Ursache der Misserfolge bei operativer Behandlung des Bronchialasthmas und ihre Beseitigung, ibid. **142**:499, 1926; Die Ursache von Misserfolgen bei Asthmaoperationen und ihre Verhütung, Centralbl. f. Chir. **53**:1278, 1926.

21. Dixon, W. E., and Ransom, F.: Bronchodilator Nerves, J. Physiol. **45**: 413, 1912.

22. Papilian, V., and Cruceanu, H.: Der Einfluss der beiderseitigen cervicalen Sympathektomie auf die Respirations Bewegungen, Cluj. Med., s. 1, 1923.

23. Fründ, H.; Die chirurgische Behandlung des Asthma bronchiale, Beitr. z. klin. Chir. **136**:581, 1926; Aussprache, Centralbl. f. Chir. **55**:2861, 1928.

24. Kaess, F. W.: Zur operativen Behandlung des Asthma bronchiale, Klin. Wchnschr. **3**:880, 1924; Ueber Erfahrungen mit der Asthma Operation, Centralbl. f. Chir. **52**:2028, 1925.

25. Glaser, F.: Die Wirkung der Sympathektomie bei Angina pectoris und Asthma bronchiale, Med. Klin. **20**:477, 1924.

26. Hesse, E.: Zur Chirurgie des Hals-, Brust- und Bauchabschnittes des sympathischen Nervensystems, Beitr. z. klin. Chir. **136**:429, 1926; Ist die Sympathektomie beim Asthma bronchiale ihren Resultaten nach als berechtigter Eingriff zu betrachten? Deutsche med. Wchnschr. **52**:870, 1926.

27. Jungmann, P., and Brüning, F.: Zur chirurgischen Behandlung des Asthma bronchiale, Klin. Wchnschr. **3**:399, 1924.

28. Witzel, O.: Die Sympathicus operation im Ring der Heilmassnahmen beim Asthma bronchiale, Klin. Wchnschr. **4**:448, 1925.

29. Fontaine, R., and Herrmann, L. G.: Experimental Studies on Denervated Lungs, Arch. Surg. **16**:1153 (June) 1928.

30. Remak, R., 1840, quoted by Fontaine and Herrmann (footnote 29).

31. Kandarazki, M.: Ueber die Nerven der Respirationswege, Arch. f. Anat. u. Entwicklung, 1881, p. 1.

32. Larsell, O.: The Ganglia, Plexuses and Nerve-Terminations of the Mammalian Lung and Pleura Pulmonalis, J. Comp. Neurol. **35**:97, 1922.

33. Brüning, F.: Aussprache, Centralbl. f. Chir. **54**:1885, 1925.

34. Herrmannsdorfer, A.: Zur Kritik der Asthma operationen, München. med. Wchnschr. **74**:1798, 1927.

35. Leriche, R., and Fontaine, R.: Résultats éloignés du traitement chirurgical de l'asthme bronchique, Bull. et mém. Soc. nat. de chir. **54**:660, 1928; Position actuelle de la question du traitement chirurgical de l'asthme bronchique, Arch. méd.-chir. de l'app. respir. **4**:1, 1928.

36. Kappis, M.: Die Frage der operativen Behandlung des Asthma bronchiale, Med. Klin. **20**:1347, 1924.

37. Daniélopolu, D.: Sur la pathogénie de l'asthma, Presse méd. **33**:1585, 1925.

38. Freund, W. A.: Zur operativen Behandlung gewisser Lungenkrankheiten, insbesondere des auf starrer Thoraxdilatation beruhenden alveolaren Emphysems (mit einem Operationsfalle), Ztschr. f. exper. Path. u. Therap. **3**:379, 1906.

39. Bircher, E.: Die Erfolge der Freundschen Operation beim Lungen Emphysem, Deutsche med. Wchnschr. **44**:225, 1918.

40. Heuer, G. J.: Pulmonary Emphysema, in Keene's Surgery, Philadelphia, W. B. Saunders Company, 1922, vol. 8, p. 403.

41. Head, J. R.: Prevention of Regeneration of the Ribs, Arch. Surg. **14**: 1209 (June) 1927.

42. Voelcker: Behandlung des Asthma bronchiale durch paravertebrale Pfeilerresektion, Arch. f. klin. Chir. **148**:522, 1927.

43. Warstat: Der Einfluss der einseitigen Extraktion der Interkostalnerven auf die Lunge und ihre tuberkulöse Erkrankung, Deutsche Ztschr. f. Chir. **138**: 437, 1917.

44. Hirschberg, quoted by Brewer in Keen's Surgery, 1919, vol. 6, p. 374.

45. Braun, quoted by Brewer in Keen's Surgery, 1919, vol. 6, p. 374.

46. Sluder, G.: Asthma as a Nasal Reflex, J. A. M. A. **73**:589 (Aug. 23) 1919.

47. Sterling, A.: The Relation of Asthma to Nose and Throat Surgery, M. J. & Rec. **125**:336, 1927.

48. Rowe, A. H.: The Treatment of Bronchial Asthma, J. A. M. A. **84**:1902 (June 20) 1925.

49. Hynek, K.: Asthma and Splenectomy, Bratisl. lekár. listy **7**:218, 1927.

50. Drey, L., and Lossen, H.: Beseitigung chronischen Bronchialasthmas durch Fernwirkung der Röntgenstrahlen bei Milzbestrahlung, zugleich ein Beitrag zur Erklärung der Röntgenstrahlenwirkung bei Asthma bronchiale, Strahlentherapie **10**:1052, 1920.

51. Phillip, A. P. N.: An Experimental Inquiry Into the Laws of the Vital Functions, Philadelphia, 1818.

52. Göbell, R.: Zur Kritik der Asthma operationen, Centralbl. f. Chir. **55**: 2858 and 2951, 1928.

53. Lengemann, P.: Aussprache, Centralbl. f. Chir. **55**:2860, 1928.

54. Kümmell: Aussprache, Centralbl. f. Chir. **55**:2862, 1928.

55. Kümmell: Der heutige Stand der chirurgischen Behandlung des Asthma bronchiale, Therap. d. Gegenw. **68**:15, 1927.

56. Leder, M.: Les résultats actuels du traitement chirurgical de l'asthme bronchique, Strasbourg méd. **88**:1, 1928.

57. Orth, O.: Zur Chirurgie des Asthmas, Vereinsbl. d. pfälz. Aerzte **40**:318, 1928.

58. Schilling, T.: Die Röntgentherapie bei chronischer Bronchitis und Bronchial asthma, München. med. Wchnschr. **57**:956, 1910.

59. Gerber, I.: Roentgen-Ray Treatment in Bronchial Asthma and Chronic Bronchitis, J. A. M. A. **85**:1026 (Oct. 3) 1925; Further Observations on the Roentgen-Ray Treatment of Bronchial Asthma and Allied Conditions, Radiology **9**:192, 1927.

60. Klewitz, F.: Ueber das Asthma bronchiale, Med. Klin. **21**:1181, 1925.

61. Ischiyama, F.: Surgical Treatment of Bronchial Asthma, Japan M. World **5**:289, 1925.

62. Rehbein, M.: Zur Indikation der Sympathikus operation bei Asthma bronchiale, München. med. Wchnschr. **72**:1885, 1925.

DECORTICATION OF THE HEART (DELORME) FOR ADHESIVE PERICARDITIS

EDWARD D. CHURCHILL, M.D.
BOSTON

Cases of adhesive pericarditis in which the patients are amenable to operative treatment may be divided somewhat arbitrarily into two groups. The commonly recognized form of the disease is that in which the mediastinal adhesions binding the pericardium to the wall of the chest dominate the picture. In other cases, however, the contraction of the thickened pericardium itself produces cardiac failure by interfering with the proper action of the heart. The recognition of the two types of the disease is of prime importance when surgical intervention is considered. It becomes obvious that no single operative procedure can be effective when the differences in the morbid anatomy are considered.

The term *mediastinopericarditis* is properly applied to that form of the disease in which a firm cicatrix in the anterior mediastinum binds the outer aspect of the pericardium to the wall of the chest. The systolic contraction of the heart is hindered, as in every contraction the cardiac muscle must meet and overcome the resistance of the rigid bony framework of the thorax. The cardiac decompensation occurring under such circumstances is attributed to the strain which this abnormal fixation to the wall of the chest throws on the heart—an organ which has already suffered myocardial damage from infection. It is not improbable that the distortion caused by the fixation of the heart during respiratory movements may also produce a relative valvular insufficiency. A positive diagnosis is more frequently made in this type of the disease, and the patient is not uncommonly referred for surgical treatment. The systolic retraction of the wall of the chest gives a strong and readily understood indication for cardiolysis.

In operating for this condition one aims to free the heart from the unyielding scar which binds it to the wall of the chest. This is readily accomplished by the removal of the cartilaginous or bony portion of the ribs overlying the heart. Such an operation is the cardiolysis of Brauer or, more correctly, *thoracolysis praecardiaca,* a term suggested by Kocher.

In the second type of adhesive pericarditis, the heart is found encased in a veritable coat of mail formed by a thickened and inelastic pericardium. In these cases of *concretio pericardii* the heart becomes so throttled by the unyielding wall of scar tissue that its chambers can no longer expand in diastole to receive the inflowing blood. A marked

degree of stasis is produced in the veins, particularly the inferior caval system. The action of such a heart has been compared by Rehn to the restricted movements of a hand in a tightly fitting glove.

As a matter of fact, all degrees of transition exist between the two types, and Volhard,[1] who has submitted an excellent description of the clinical picture of concretio pericardii, expressed the feeling that the difference lies more in the degree of contraction than in the type of adhesion.

Patients in the first named group with adhesions between the pericardium and the anterior wall of the chest may progress until they show a more or less high degree of decompensation with the classic signs and symptoms of cardiac passive congestion. In addition, there is present the characteristic retraction of the precordial area of the wall of the breast with every systole and a bulging back during diastole. The presence of a marked thrill of the thoracic wall indicates a still powerful heart action and a competent diastolic filling of the chambers. On the other hand, when the heart is throttled by a contracted pericardium, the clinical picture is characterized by a striking disproportion between the high degree of cardiac passive congestive symptoms and the slight objective cardiac signs. In the words of Volhard: [1]

> We find all that belongs to the general picture of marked cardiac decompensation—edema, effusions in the body cavities, liver swelling, dyspnoea on exertion, incapacity for work, but we fail to find the signs in the heart that we are accustomed to associate with such a condition and that account for the symptoms. We find no widening, rather a small heart; no apex impulse; no thrill of the chest wall; usually pure but strikingly soft sounds. The unfavorable diastolic filling of the heart produces a small, weak pulse, often smaller with inspiration. By fluoroscopy the heart appears to stand still, so slight are the evidences of heart motion. Very important but not peculiarly specific and present in both types is the lack of elevation of the anterior wall of the chest in breathing that Wenckebach has demonstrated.
>
> But the finding that particularly indicates a seriously impeded diastole is the marked distention of the cervical veins, that do not empty in the upright posture, and especially in the upright position show a very characteristic double collapse in systole and diastole.
>
> Moritz-Tabora measured the venous pressure in the arm veins and found very high values of 200 to 300 mm. of water. This accounts for a marked degree of liver congestion and the tendency to hydrothorax and early ascites, even before edema of the legs supervenes.
>
> These "ascites praecox" can for years be subjected to countless tappings, unnecessary exploratory laparatomies, Talma operations, and false diagnoses.

The most striking single characteristic of the picture is marked venous stasis with a small heart. It is impossible to conceive of a

1. Volhard and Schmieden: Klin. Wchnschr., 1923, no. 1, p. 5.

distensible right auricle and ventricle remaining undilated in the presence of such a high degree of venous stasis—and it is exactly this lack of overfilling of the right side of the heart that led Volhard to employ the term "Einfluss stauung" or "inflow stasis." In the treatment of a patient in this type of case it is clear that there is nothing to be expected from the removal of the bony wall of the chest. Nothing less than a deliverance of the heart from its cicatricial coat of mail can influence the course of the disease.

Before discussing the literature which bears on the subject of decortication of the heart, an account of a case in which the operation was successfully performed will be presented. The patient was referred to me by Dr. Paul D. White to whom I am indebted for the diagnosis and medical care of the patient.

REPORT OF CASE

History.—C. S. was an American school girl, aged 18. At the age of 5 the patient was troubled by occasional spells of dyspnea, and her physician said that she had an enlarged liver and ascites. When 14 years of age, she had a succession of peritonsillar abscesses which were accompanied by attacks of dyspnea on exertion and "smothering spells." Again she was told that she had ascites.

First Admission.—On Jan. 26, 1925, at the age of 15, she was admitted to the medical service of the Massachusetts General Hospital, where a diagnosis was made of chronic adhesive pericarditis, perihepatitis, ascites and chronic tonsillitis. The patient showed no respiratory distress. The entire right hemithorax moved with each heart beat. The heart itself was enlarged, the apex impulse being in the fifth interspace, 8.5 cm. to the left of the midsternal line. The apex impulse shifted with change in position. There was no Broadbent's sign. A well defined systolic murmur was heard about the apex transmitted to the axilla. No diastolic murmurs were heard. The heart sounds were of good quality and regular with a third sound at the apex. There was no evidence of pulmonary congestion, but the liver was enlarged, the edge extending 6 cm. below the costal margin. There was a moderate degree of ascites. The cervical veins were slightly engorged and pulsating. Digitalis produced no definite change in the condition of the heart.

Second Admission.—On June 19, 1925, the patient was readmitted to the Medical Service. In the interval she had had her tonsils removed. As there was a definite increase in the ascites, 4,500 cc. of pale fluid was withdrawn by abdominal paracentesis. Inoculation into a guinea-pig gave negative results. The total protein content of the abdominal fluid was 4.8 per cent; that of the plasma was 6.4 per cent. An electrocardiogram showed slight left axis deviation. The vital capacity was 2,600 cc. She remained on the medical wards for one month on treatment with diuretics without effect.

On Aug. 18, 1927, she was seen in the cardiac clinic of the outpatient department. Two months after discharge from the hospital, 10 quarts of abdominal fluid had been removed by her physician. Her activities had been restricted during the two year interval but not entirely. She had been able to walk and to climb stairs. Edema of the legs had appeared within the past month. Examination of the heart now showed the apex impulse fixed in position. A few moist râles were heard at the left base, and there was definite ascites. She was advised to go home, remain in bed, and take digitalis and theophylline, U. S. P. (theocin).

Three weeks later it was noted that there was still well marked edema of the shins which had not disappeared with the digitalization.

On April 26, 1928, the following note was made in the cardiac clinic: "Doing poorly. In bed a good bit of the time throughout the winter. Legs and abdominal wall edematous. Abdomen tapped in February. Takes no digitalis. Had theocin a month ago without effect. Physical examination as before except for cyanosis which is now present."

At this time, the following letter was written by Dr. Paul White to her physician: "Yesterday morning in the Cardiac Clinic here, I saw C. S. again and found her in poor condition. She certainly has had a very miserable time and I am afraid there is not much can be done to help her. There seems little doubt that pericarditis must be at the back of her trouble. Probably she has a good deal of mediastinal involvement and disability of the heart itself. . . . I would suggest resuming digitalis 1½ grains once daily for a few days, then once daily for two weeks. If after two or three weeks she is not better I would suggest that she come to the hospital again with the thought to consider cardiolysis, in case there is any chance of freeing the heart of some of the extra work that it is doing. I suppose, however, that the prognosis is rather poor at the best."

Third Admission.—The patient entered the Massachusetts General Hospital for the third time on June 8, 1928. For the past month she had been confined to bed and was orthopneic. She was dyspneic on slight exertion, and the edema of her lower extremities had markedly increased. On physical examination the heart seemed fixed in position, and in addition to the observations already noted a pulsus paradoxus was observed. Signs of fluid were found at both bases. There was extreme edema of the lower extremities extending upward over the sacrum. The vital capacity was 1,600 cc. as compared with 2,600 cc. three years before. Roentgen examination showed dulness of both bases obliterating the outlines of the diaphragm, rising to the level of the fourth rib on the right. The heart shadow appeared large and prominent in the region of the left ventricle. From the lateral aspect the sternum seemed to move normally away from the mediastinal shadow on deep inspiration. There appeared to be no adhesions between the sternum and the mediastinum. There was considerable increase in the dulness in the right cardiophrenic angle with some limitation of diaphragmatic excursion in this region. She was given an organic mercury compound in repeated doses, but the slight diuresis caused only a transient loss of weight. On July 16, 2,500 cc. of clear fluid was removed from the abdomen.

In considering the case of C. S. with a view to planning operative relief, it was felt from the outset that nothing was to be gained by the Brauer operation. It is true that three years before, the cardiac pulsations were described as being forcefully transmitted to the wall of the chest and the heart appeared to be enlarged. A definite systolic retraction of the ribs and interspaces had never been observed, however, and now, in contrast, the heart seemed small, particularly in relation to the high degree of venous stasis. The pulsations were but feebly transmitted to the wall of the chest, and the sounds were distant and muffled. Roentgen examination failed to show evidence of adhesions between the pericardium and the anterior wall of the chest. The signs and symptoms seemed clearly to be those of the "inflow stasis"

or impeded diastolic filling so vividly described by Volhard and Schmieden.[1]

Certain physiologic considerations have more than a mere theoretical bearing in planning the operation of decortication of the heart. The unfortunate results in several of the cases of pericardial resection that have found their way into the literature have emphasized the importance of having clearly in mind an accurate knowledge of the pathologic changes in the individual case. Schmieden [2] has given a helpful analysis of the causes of the successes and failures in his series of seven cases.

At the outset, one is forced to admit that no reliable criteria exist for determining the capability of the cardiac musculature to withstand the suddenly increased load. Numerous observations and experiments [3] have demonstrated that under the conditions of normal life the pericardium plays no important part in supporting the wall of the heart. Conditions may be different, however, when the myocardium has been damaged by infection. Further, in an individual case it may be difficult to differentiate the symptoms of cardiac failure due to mechanical factors from those referable to myocardial weakness. If improvement results from digitalis therapy, it is probable that the myocardial insufficiency is playing an important rôle in the case under question. If improvement does not follow rest and the administration of digitalis, the mechanical factors may be considered paramount, but an underlying myocardial weakness cannot be excluded.

Of equal importance to the state of the myocardium and a point concerning which one may more readily inform oneself is the matter of the balance between the action of the right and left ventricles. It is of the greatest importance to ascertain the extent to which the scar involves these two chambers. If the output of the right ventricle is suddenly increased by decortication while the left ventricle remains encased in scar, the area of venous stasis is merely transferred from the caval systems to the lungs, and diaster follows. This very happening has undoubtedly been responsible for some of the deaths on the operating table. If the left side of the heart is involved in the scar, it must be liberated before freeing the right chambers. Schmieden [2] now advises a transpleural approach for this purpose.

Fluoroscopic examination in different positions with special observation of the movements of the ventricles is invaluable in ascertaining the extent to which each is involved in the scar. Other signs of

2. Schmieden, V., and Fischer, H.: Ergebnisse des Chirurgie u. Orthopädie **19**:98, 1926.

3. Beck, C. S., and Moore, R. L.: The Significance of the Pericardium in Relation to Surgery of the Heart, Arch. Surg. **11**:550 (Oct.) 1925. Grant, R. T.: Heart **13**:371, 1926.

encasement of the left side of the heart are effusions in the pleural cavities, stasis in the pulmonary circuit and a widening of the cardiac shadow to the right.

In the patient under consideration, fluoroscopy showed the heart shadow to be large and prominent in the region of the left ventricle. Further, the lack of improvement with digitalis gave evidence that the apparent cardiac failure might fairly be attributed to purely mechanical factors. Operation was proposed therefore, for the release of the right ventricle by resection of the adherent pericardium.

Operation.—On July 18, 1928, with the patient under ether anesthesia, an incision was made extending along the line of the second rib to the middle of the sternum, bearing directly downward to the xiphoid, then laterally along the seventh costal cartilage (fig. 1). The skin flap so outlined was reflected outward with the pectoralis muscle. The cartilages of the third, fourth, fifth, sixth and seventh

Fig. 1.—Incision three weeks after the operation.

ribs were resected, taking in addition 1 inch of the bone of the fourth and fifth ribs, respectively (fig. 2). The internal mammary vessels were ligated in the second interspace, and the intercostal muscles with the posterior layer of the perichondrium of the costal cartilages were removed. The left pleural reflection was retracted laterally by blunt dissection. The anterior surface of the pericardium appeared as a firm white scar which did not transmit the pulsations of the underlying heart. An incision was made through the pericardium which was found to be 1.5 mm. in thickness. When the left ventricle was reached, the pericardium was carefully separated from the surface of the heart, the dissection being carried medially over the right ventricle. The adhesions between the visceral and parietal surfaces of the pericardium were in the main separated by the finger without causing any bleeding. In a few places over the right ventricle scissor dissection was used. The pericardium was removed in small fragments as it was freed. In the end there was a defect as large as the palm of one's hand, the heart herniating through this opening as though making ready use of the space which had been made available (fig. 3). The left half of the sternum was removed with rongeurs, and the dissection of the pericardium was carried as far as the auricle. The heart was then raised and separated from

Fig. 2.—Resected portions of third to seventh costal cartilages and rib ends.

the diaphragmatic pericardium until the vena cava could be seen. The diaphragmatic pericardum was much thickened and was contracted in one place into a strong fibrous band, 8 mm. in diameter, which seemed to rest in the angle between the inferior vena cava and the right auricle like a sling (fig. 4). This band was studded with calcareous deposits and was attached anteriorly to the surface of the diaphragm in the region of the xiphoid. It was resected by a V-shaped incision the apex of which lay at the vena cava. Following this, the edges of the pericardium retracted and revealed the musculature of the diaphragm beneath. Adhesions about the apex of the heart were loosened, but attention was chiefly directed to the right side of the heart and the diaphragmatic pericardium. The reflection of the right pleura was stripped back by blunt dissection, neither pleural cavity being entered. At the conclusion of the operation the skin

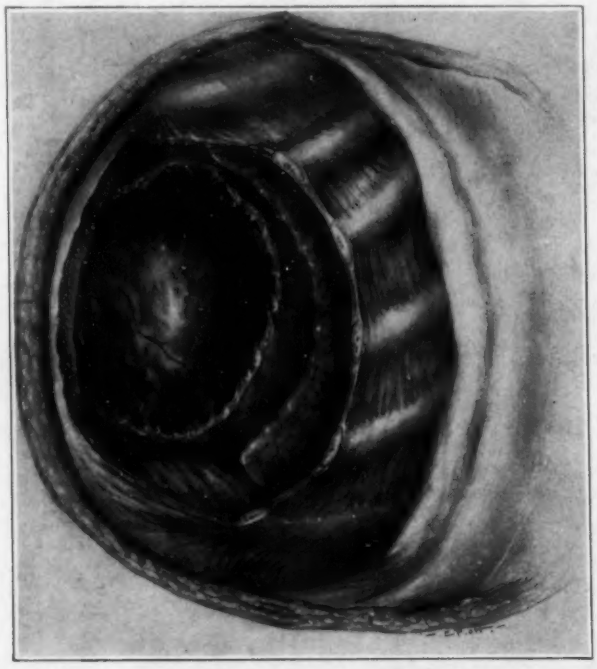

Fig. 3.—Window in the thickened pericardium being created by resection.

and muscle flaps were turned back into position, leaving the surface of the heart in direct contact with the under surface of the pectoralis muscle. The apex impulse was now transmitted forcefully through the tissues of the breast. For a time during the freeing of the adhesions about the vena cava adequate exposure necessitated pressing on the right side of the heart with the flat surface of the hand. This distinctly interfered with the filling of the heart, and the anesthetist reported that the blood pressure could not be obtained. Conditions returned to normal, however, when the hand was removed. The patient left the table in excellent condition. Convalescence was without notable incident. The edema of the extremities rapidly subsided, less edema being present in the legs ten days after the operation than at any time during the preceding year. Diuresis was evident in the relation of the fluid output to fluid intake, the most notable degree occurring on the fifth day postoperatively.

On August 7, the patient was allowed to sit up in a chair. There were no ill effects. She had lost 20 pounds (9 Kg.) of weight, most of which, of course, was accounted for by the disappearing edema. Her strength rapidly increased, and on August 16, one month after the operation, she was discharged from the hospital.

On September 7, seven weeks after the operation, she reported at the cardiac clinic and was found to have no edema of the feet or legs. The enlarged liver was still palpable 6 cm. below the costal margin, but there was no ascites. Improvement continued to be rapid, and she was advised to increase her activities.

On March 7, 1929, she was found to be in excellent spirits and had gained considerably in weight and strength during the winter. She was able to walk

Fig. 4.—Further stage in pericardial resection showing the elevation of the heart and freeing of diaphragmatic pericardium. The bandlike elevation is shown extending backward toward the inferior vena cava. This band was resected with the adjacent scar.

four miles a day without any shortness of breath. In coming to the clinic she said that she had run a considerable distance to catch the train. There is now no edema, and the abdomen shows no evidence of ascites. The pulsation of the heart is palpable as a forceful thrust in the window to the left of the sternum.

On Aug. 27, 1929, a report from Dr. Paul D. White referred to the patient as being in a "splendid" condition.

The question of reformation of the adhesions in this case must be left for the future to settle. In the cases reported in the literature such an occurrence has not been found to be a real danger, the usual course

being one of continued and progressive improvement. It has been suggested on the basis of experimental work that the pericardial defect be repaired with a fat or fascia transplant.[4] I agree with Schmieden's policy of not adding a procedure of this nature to the operation unless further clinical experience makes it seem imperative.

REVIEW OF LITERATURE

Weill,[5] in 1895, recognized that the rational treatment of this type of adhesive pericarditis lay within the purview of surgery. This view was expressed in the following words:

> Lorsque la symphyse est arrivée au stade fibreux, elle est complètement émancipée de sa cause, et les moyens médicaux sont illusoires. On n'a jamais songé à faire de débridement dans ce cas, moins peut-être par résignation, que par incertitude du diagnostic. Il y aurait lieu de faire une tentative de ce genre, qui consisterait à libérer une partie du coeur, la point par exemple et la face antérieure. . . . C'est à la chirurgie qu'il appartiendra un jour de délivrer le coeur de la coque qui l'étrangle.
>
> (After the adhesions have reached a fibrous stage, they act independently of their original cause, and medical therapy is illusory. One has never dreamed of attempting a débridement in such a case, less perhaps from resignation than from the uncertainty of diagnosis. There would be good cause to make an attempt of this kind, designed to liberate a part of the heart, the apex for example, and the anterior surface. . . . It will one day come within the province of surgery to deliver the heart from the shell which strangles it.)

Three years later (1898), the operation of decortication of the lung gave Delorme[6] the idea that the same principles could be applied to a heart encased in an adherent pericardium. Detailed observations were made on cadavers, and it was found that adhesions between the heart and pericardium could be freed either with the scissors or bluntly with the finger. The operation of Delorme is not infrequently referred to as a lysis of intrapericardial adhesions followed by closure of the pericardium. As a matter of fact, Delorme recommended an actual excision of a portion of the pericardium in suitable cases. Further, when the adhesions are found to be too closely adherent to permit of a separation, he advised a section of the pericardium at its diaphragmatic attachment anteriorly.

Delorme[7] plead for the adoption of his proposed operation in numerous communications addressed to the clinical societies of Paris. His

4. Klose, H.: Arch. f. klin. Chir. **117**:138, 1921.

5. Weill, E.: Traité des maladies du coeur chez les enfants, Paris, 1895, p. 128.

6. Delorme, E.: Gaz. d. hôp., 1898, p. 1150.

7. Delorme, Edmond: Bull. et mém. Soc. de chir. de Paris **24**:918 (Oct.) 1898; Soc. méd. d. hôp. de Paris, 3 series **37**:318, 1914; Gaz. d. hôp. **86**:2269 (Dec. 16) 1913; ibid. **87**:341 (Feb.) 1914.

proposals met with slight favor, however, and in 1902 the simpler procedure designed by Brauer [8] was announced from Germany. Cardiolysis by the simple resection of ribs and costal cartilages gained popularity, and the theoretical principles so carefully worked out by Delorme were discarded as being too unnecessarily hazardous for clinical application.

Carl Beck, speaking before the American Medical Association in 1901,[9] briefly referred to the possibilities of surgical relief in adherent pericarditis.

Rehn [10] is commonly accredited with pointing the way toward the practical application of the theories of Delorme, and was the first operator to report the results in cases in which an excision of a portion of the pericardium had been carried out. It is to be noted, however, that Sauerbruch [11] as early as 1913 had freed the heart and resected a portion of the pericardium in a patient who had been confined to bed by dyspnea and who showed general edema. The patient was reported as being symptom-free and able to work eleven years after the operation.

In 1913, Rehn [12] expressed himself as being doubtful whether a heart which is encased in scarred tissue could be freed. He considered the intrapericardial lysis of adhesions to be impracticable because of the rapid reformation of new adhesions. As a matter of fact, this very thing had happened to mar the good result which he had obtained in a child. In a later communication, Rehn [13] reported the results of extensive studies in the pathologic physiology of the various types of adhesive pericarditis. He then clearly described the technic and application of pericardial resection which he had carried out in four cases.

Case reports of successful operations have appeared with increasing frequency, particularly from Germany. Schmieden [2] has had a more extended experience than any other single operator, and I have already referred to his admirable analysis of the physiologic mechanisms involved in the operation.

The reported operations or attempts at operation have been listed in the accompanying table. In all, there have been collected the data in thirty-seven cases in which an operation was performed, five (cases 8, 9, 10, 11, 31) of which were interrupted. The deaths directly attributable to the operative procedure number seven (cases 6, 7, 12, 14, 19,

8. Brauer, L.: Arch. f. klin. Chir. **71**:258, 1903-1904; München. med. Wchnschr. **49**:1072, 1902.

9. Beck, Carl, in discussion on Norbury, F. P.: Some Points in the Treatment of Pericarditis, J. A. M. A. **37**:1585 (Dec. 14) 1901.

10. Rhen, L.: Berl. klin. Wchnschr., 1913, p. 241; Arch. f. klin. Chir. **102**:1, 1914; Med. Klin. **16**:999, 1920.

11. Sauerbruch, Ferdinand: Die Chirurgie der Brustorgane, Berlin, 1925, vol. 2, p. 298.

12. Rehn (footnote 10, first reference).

13. Rehn (footnote 10, third reference).

Results of Operation in Thirty-Seven Cases Reported in the Literature *

Case	Author	Operator	Age	Sex†	Result
1	Rehn [13]	Rehn	..	..	Primary result good; benefit not lasting because lesion was tuberculous
2	Rehn;[13] Picard (Med. klin. **16**: 234, 1920)	Rehn	6	♀	Primary result good; benefit not lasting because lesion was tuberculous
3	Rehn [13]	Rehn	13	♀	Excellent; died later due to recurrence of rheumatic fever
4	Rehn [13]	Rehn	14	♂	Excellent; died 1½ years later of influenza
5	Sauerbruch [11]	Sauerbruch	28	♂	Complete relief of symptoms 11 years after operation
6	Sauerbruch [11]	Sauerbruch	21	♂	Died 18 days after operation of cardiac insufficiency
7	Sauerbruch [11]	Sauerbruch	28	♀	Died 24 hours after operation of exhaustion
8	Sauerbruch [11]	Sauerbruch	39	♂	Operation interrupted because of cardiac irregularity; good result nevertheless; died 4 years later of renal tuberculosis
9	Volhard and Schmieden [1]	Henle	..	..	Attempt abandoned because of tearing right ventricle
10	Volhard and Schmieden [1]	Heuck	..	..	Attempt abandoned because of tearing right ventricle
11	Volhard and Schmieden [1]	Brauer	..	..	Attempt abandoned because of tearing right ventricle
12	Volhard and Schmieden [1]	Voelcker	..	♀	Weak girl, died soon after operation
13	Volhard and Schmeiden [1]	Voelcker	..	♂	Young man, died 14 days after operation of severe tuberculosis
14	Volhard and Schmieden [1]	Voelcker	..	..	Incomplete removal, died; autopsy showed unyielding scar still encasing the heart
15	Volhard and Schmieden [1] Schmieden and Fischer [2]	Schmieden	30	♂	Two operations: (1) small section of pericardium removed from right ventricle; temporary relief; (2) transpleural decortication of left ventricle; symptomatic cure 4 years after operation
16	Volhard and Schmieden [1] Schmieden and Fischer [2] Schmieden (München. med. Wchnschr. **69**: 177, 1922)	Schmieden	46	♂	Complete relief of symptoms
17	Schmieden (Zentralbl. f. chir. **51**: 46, 1924) Schmieden and Fischer [2]	Schmieden	22	♂	Temporary improvement; died 3 weeks later; autopsy showed extensive involvement of cardiac muscle
18	Schmieden and Fischer [2]	Schmieden	18	♂	Complete relief of symptoms
19	Schmieden and Fischer [2]	Schmieden	18	♂	Died on table at end of complete operation from dilatation of right heart
20	Schmieden and Fischer [2]	Schmieden	..	..	No particulars concerning sixth case of Schmieden's series; listed as "improved"
21	Schmieden and Fischer [2]	Schmieden	5	♂	Postoperative course complicated by extensive wound infection, pneumonia and empyema; improved
22	Bittrolff (München med. Wchnschr. **71**: 517, 1924)		18	♀	Improved markedly; Talma operation performed later
23	Délagéniere (Gaz. d. hôp. **86**: 1033 [June 5] 1913)		28	♀	Relief of symptoms; not definitely stated that pericardium was resected
24	Guleke and Lommel (Klin. Wchnschr. **4**: 737, 1925)		27	♂	Excellent result; venous pressure reduced from 165 mm. to 42 mm.
25	Kirschner and Matthes (Deutsche med. Wchnschr. **52**: 221, 1926)		22	♂	Excellent result 2 months after operation
26	Koennecke (München. med. Wchnschr. **74**: 675, 1927)		21	♂	No improvement; advancing cachexia attributed to hepatic insufficiency
27	Koennecke (München. med. Wchnschr. **74**: 675. 1927)		9	♂	Excellent result
28	Grote (Mitt. a. d. Grenzgeb. d. Med. u. Chir. **38**: 556, 1925)	Sattler	20	♂	Excellent result
29	Ljungdahl and Tengwall (Acta chir. Scandinav. **59**: 480, 1923)		46	♂	Complete relief of symptoms 2 years after operation
30	Enderlen (Zentralbl. f. chir., 1925, p. 589) Sauerbruch [11]	Enderlen	19	♂	Improvement for 3 months; recurrence of symptoms with death

* A case report referred to by Guleke (Mitt. a. d. Grenzgeb. d. Med. u. Chir. **40**: 252, 1927) but which has not been available is that of Tilmanns in which the patient is said to have died of recurrence of symptoms in nine months. Minkin (Vestnik. Khir. **10**: 52, 1927) is also said to have reported a case of pericardial resection.

† In this column, ♂ indicates male, and ♀, female.

Results of Operation in Thirty-Seven Cases Reported in the Literature—Continued

Case	Author	Operator	Age	Sex	Result
31	Lilienthal (Thoracic Surgery, 1925, vol. 1, p. 422) Lossen and Kahl (Zentralbl. f. Chir. **51**: 2585, 1924)	Lilienthal..	31	♀	Right auricle torn in attempting separation; operation abandoned; slow recovery
32	Hanebuth and Naegeli (Med. Klin. **23**: 1253, 1927)	.....	..	♂	Died of cardiac insufficiency 1 hour after operation
33	Läwen and Matthes (Deutsche med. Wchnschr. **54**: 617, 1928)	.....	24	♀	Improved
34	Cutler and Beck (Nelson's Loose-Leaf Living Surgery, vol. 4)	Cutler.....	..	..	Died 1 hour after operation from myocardial failure
35	Churchill.....	Churchill...	18	♀	Complete relief of symptoms 14 months after operation
36	Delorme (Progrès méd., 1924, p. 457); Hallopeau (Bull. et mém. Soc. nat. de chir., 1921, T. 47, p. 1120)	Hallopeau.	16	♀	Operation performed during search for encapsulated rheumatic effusion which was not found; complete relief of symptoms
37	Delorme (Progrès méd., 1924, p. 457); Hallopeau Bull. Soc. de pédiat. de Paris, 1923, T. 21, p. 206)	Hallopeau.	7	♂	Accompanied by acute osteomyelitis of femur; pericardium resutured; recovery

32, 34) or 21.8 per cent of the cases in which operation was completed; two patients (cases 13, 26) showed no improvement (6.2 per cent); the improvement was transitory, and the patient died of the original disease in four cases (1, 2, 17, 30), or 12 per cent; in the nineteen remaining cases (59 per cent), the result was excellent, and frequently there was almost complete relief from symptoms. Three of the patients in the latter group died of intercurrent disease.

SENSIBILITY OF THE EXPOSED HUMAN HEART AND PERICARDIUM *

JOHN ALEXANDER, M.D.

A. GARRARD MACLEOD, M.D.

AND

PAUL S. BARKER, M.D.

ANN ARBOR, MICH.

Knowledge of cardiac and pericardial sensibility, as we have found it presented in published reports, is meager and incomplete. There is little agreement among the reporters as to the facts. This is largely due, we believe, to the scarcity of opportunity for careful observation on the open pericardial cavity of patients who are neither narcotized, shocked nor very toxic.

We recently availed ourselves of an unusual opportunity to investigate extensively the sensory reactions of the exposed human heart and pericardium to various forms of stimulation.

REPORT OF CASE

Our patient was a telephone linesman, aged 30, who was admitted to the University Hospital on Feb. 2, 1929, with typical history, symptoms and signs of a basal lobar pneumonia of the left lung of three days' duration. During the next twelve days the signs and symptoms of the disease subsided, but on the following day there were a sharp rise in temperature, precordial pain and friction. Pericarditis was diagnosed. Pericardial fluid and a pulsus paradoxus followed, and 75 cc. of serosanguineous fluid containing *Streptococcus hemolyticus* and *S. viridans* was withdrawn by aspiration. Two days later extrapleural pericardiostomy was performed under local and regional anesthesia without infiltrating the pericardium or pleura. After portions of the fifth and sixth left costal cartilages were removed, the pericardium was incised longitudinally from the fourth intercostal space to the diaphragm, a distance of 6 cm. Two hundred and forty cubic centimeters of serofibrinous fluid was evacuated.

There were now exposed to view the lower anterior surfaces of the right and left ventricles, a portion of the inner surface of the pericardium, as well as a portion of the pericardial surface of the diaphragm (fig. 1). In addition, the entire surface of both ventricles, a part of the right auricle and all the pericardium overlying these portions of the heart, were within reach of certain of our examining instruments. The observations on the reactions to various sensory stimuli that are to be described, were then carried out. The condition of the patient

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* From the Departments of Surgery and Internal Medicine, University Hospital, University of Michigan Medical School.

* Throughout this article, the term "pericardium" will be used to denote the parietal pericardium and the term "heart" to denote myocardium and epicardium or visceral pericardium.

during these and subsequent observations was satisfactory, and he was not harmfully influenced by them. At the beginning of the operation his blood pressure was 112 systolic and 60 diastolic, his pulse rate 100 and his respirations 22. At the end of the operation they were, respectively, 118 and 60, 96 and 32. The pulse rate never rose above 108.

The operation was completed by sewing the incised edges of the pericardium to the pectoral fascia. This afforded excellent continuous drainage without the use of any tube or tissue. A surgical solution of chlorinated soda (Dakin's solution) and later 0.1 per cent solution of mercurochrome were introduced into the pericardial cavity six times daily, and drainage was aided by aspiration of the upper anterior and posterior recesses of the pericardial cavity with a catheter and syringe. Eleven days after operation all streptococci had disappeared, and six-

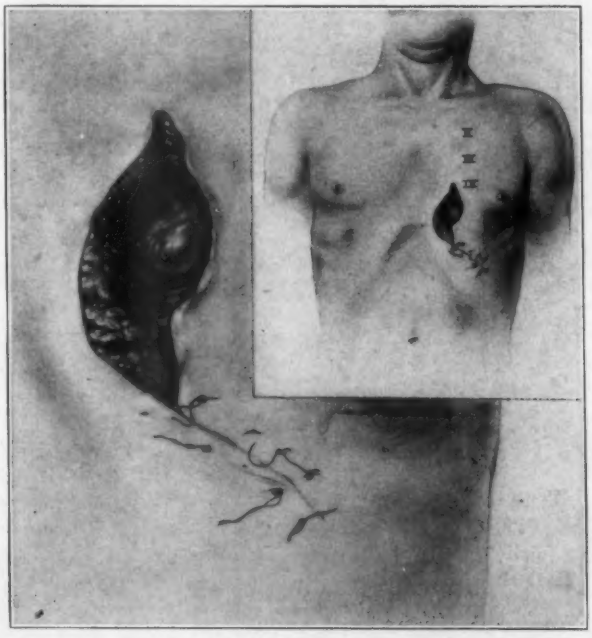

Fig. 1.—Drawings to scale of extrapleural pericardiostomy wound five days after operation. Part of the lower anterior surface of the right ventricle and a lesser part of the left ventricle are exposed. The diaphragm appears beneath the heart. The needle wound from the pericardial paracentesis may be seen in the left costoziphoid angle.

teen days after operation no organisms could be found by smear, although diphtheroids and a few *Staphylococci aurei* were present by culture. In spite of this adequate control of infection in the pericardial cavity, the temperature and pulse did not improve correspondingly. This was attributed to residual infection in the lungs, of which there were signs.

As the pulse had become paradoxic, as the systolic blood pressure had dropped from 112 to 104 and as the pericardial cavity was surgically clean, we felt that the exposed heart should now be covered to combat further disabling thickening of the epicardium. This was done twenty-one days after first establishing drainage, by sliding a flap of skin and pectoral muscle over the opening, with the

patient under nitrous-oxide-oxygen anesthesia and in the Trendelenburg position. Just before operation the blood pressure was 104 systolic and 70 diastolic, the pulse rate was 108 and respirations 26. Twenty minutes later, toward the end of the operation, the systolic pressure was 92 and the diastolic 80, the pulse rate was 140 and respirations 48; thereafter the pulse rate and blood pressure could not be obtained. A state of paroxysmal auricular tachycardia with a rate of 192 at the heart persisted until death the following day. Also there were cyanosis and increasing dyspnea with signs of consolidation of both lungs.

At necropsy there were partly unresolved pneumonia of the left lower lobe and fresh consolidation of the remaining lobes of both lungs. Also there were a narrow empyema containing 140 cc. of pus, between the mediastinum and left lung, and a separate globular empyema of 200 cc. capacity in the costovertebral gutter directly back of the heart. The heart was not dilated and the pericardial cavity was clean, without any pocketing of pus (figs. 2 and 3). The thickness of the epicardium of the left ventricle twenty-three days after the onset of the pericarditis was as follows: base, anteriorly, 2 mm.; apex, anteriorly, from 3 to 6 mm.; base, posteriorly, 3 mm. or more, not including 2 mm. of fat; apex, posteriorly, 5 mm. or more, not including 1 mm. of fat. The thickness of the epicardium of the right ventricle was: base, anteriorly, 3 mm.; apex, anteriorly, from 3.5 to 4 mm.; base, posteriorly, 1.5 mm.; apex, posteriorly, 3.5 mm. The thickness of the epicardium of the right auricle, posteriorly, was 3 mm.

EXPERIMENTAL OBSERVATIONS

Reaction to Various Stimuli.—Investigations of the sensory reactions of the heart to various stimuli were carried out during the course of the pericardiostomy; during the frequent dressings; during several occasions when the heart was stimulated electrically to produce extrasystoles for electrocardiographic study; and during a period especially devoted to a systematic study of sensation sixteen days after operation, at which study Dr. Julian Moore aided us. During none of these experiments was the patient shocked or narcotized, except that prior to operation he had had 0.1 Gm. of morphine sulphate and the operation was conducted under local and regional anesthesia of the thoracic wall, but without direct infiltration of the pericardium. As the left side of the diaphragm was seen to be moving in the wound at each examination, it may be concluded that the motor and presumably the sensory paths of the left phrenic nerve were open.

The various points stimulated on the surface of the heart, and the inner surface of the pericardium, including the diaphragmatic pericardium, have been arbitrarily numbered for descriptive purposes in recording results (figs. 2 and 3). The location of the points that were exposed to view is exact. The position of those points that are between the heart and pericardium and out of sight has been carefully estimated and may be considered as accurate within fairly narrow limits. It is obvious that when an examining instrument was introduced far into the pericardial cavity, it was in contact with both heart and pericardium and that the produced sensation might have come from either. But when direct stimulation of the heart where it was not in contact with the pericardium did not produce the sensation produced by stimulation of heart and pericardium simultaneously, it may reasonably be concluded that this sensation came from the pericardium alone.

None of the stimuli used in these experiments apparently disturbed the rate, rhythm or force of the heart, except that electrical stimulation produced extrasystoles, and pressure of a catheter caused lessened excursion of the heart between systole and diastole, as noted subsequently. One of the two reflexes seen to be

produced by our manipulations was the "squirming" of the body and extremities when severe pain was caused by electrical stimulation of the heart and by certain stimuli of the pericardium; these movements may, of course, have been partly or wholly voluntary. The other reflex, the stimulation of coughing on irrigating the pericardial cavity, will be described in the section devoted to pressure sensation. No other reflexes were observed.

Pressure on the inner surface of the anterior pericardium caused reference of pain to the chest or abdomen. No other stimulus to the heart, pericardium or diaphragm caused reference of sensation to any part of the body. On several

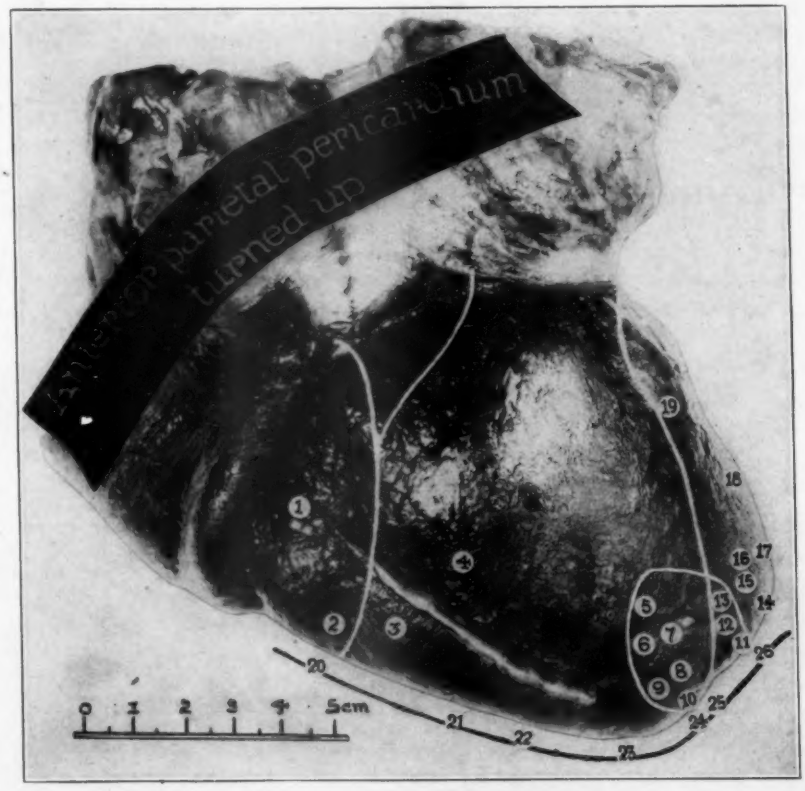

Fig. 2.—Anterior surface of heart after death. The interventricular, right auriculoventricular, and aorta-pulmonary artery sulci and the position of the pericardiostomy opening are shown by white ink. The diaphragm is represented by a black line. The numbers indicate points on the cardiac surface to which reference is made in the text.

occasions the patient was specifically asked about reference of sensation to the abdomen, back, shoulder, neck, arm and larynx.

Light touch with the tip of a finger or the end of a blunt-nosed hemostat to those portions of the ventricles and diaphragmatic pericardium (points 5, 6, 12, 13, 23, 24, 26) [1] exposed in the wound was not perceived as touch or any other

1. Throughout this article the numerically designated points refer to the position of correspondingly numbered points in figures 2 and 3.

sensation. Rubbing the ventricles (points 7, 10, 11, 12) rapidly for summation of stimuli, but not heavily, with the convex surface of a hemostat was felt as local pressure and not as pain.

Heavy pressure on the lower anterior and diaphragmatic surfaces of the ventricles (points 9, 12, 31, 33) with the convex surface of a curved hemostat (so heavy that the ventricular wall was partly invaginated, and with each systole the instrument was pushed away for a distance of about 1 cm.) was scarcely felt, and then only as local touch. It is possible that this sensation may have arisen in the posterior pericardium as a result of the heart being pushed against it.

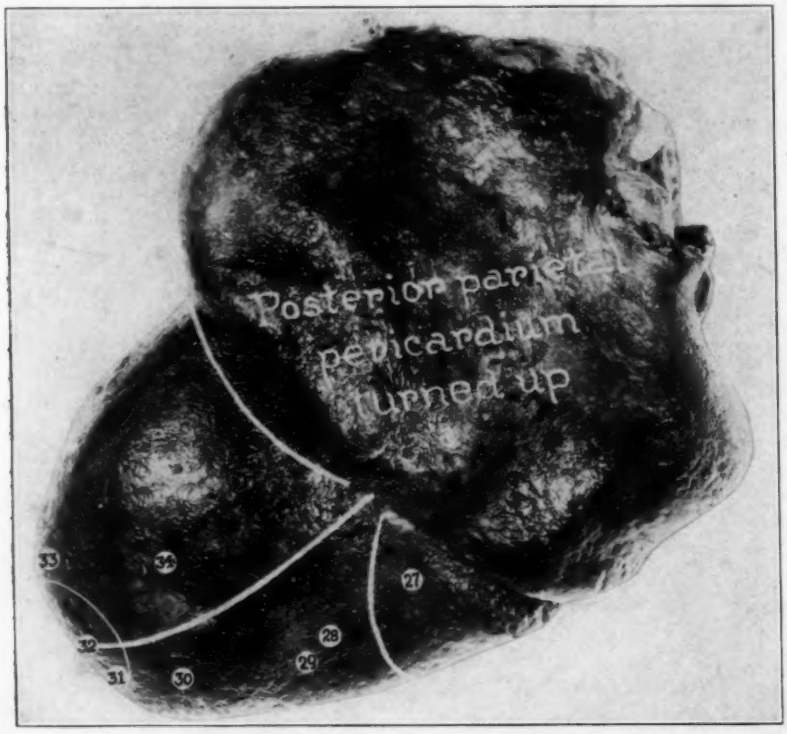

Fig. 3.—Posterior surface of heart after death. The interventricular, right and left auriculoventricular sulci, and the position of the pericardiostomy opening are shown by white ink. The numbers indicate points on the cardiac surface to which reference is made in the text.

Pinching the lower anterior surface of the left ventricle (points 12, 14) with a 1 mm. deep bite of an Allis forceps caused no pain.

Pressure on the diaphragmatic pericardium (points 20, 21, 24, 26) was not identified as touch or pain but was described as "a feeling" or "sort of pressure." One point (point 24) beneath the right ventricle once had a sensation of slight pain.

Pressure forward against the inner surface of the pericardium at the right edge of the sternum in the fourth and fifth interspaces (points 1, 2) was felt as a sharp pain which radiated horizontally backward to the right midaxilla. The patient was able exactly to localize the position of the tip of the hemostat by

touching the overlying skin with the tip of his finger. Similarly induced pressure against the third left costal cartilage (point 19) was felt as pain which spread downward toward the left hypochondrium. Heavy pressure with the end of a hemostat against the posterior pericardium opposite both the right and the left ventricles (points 29, 30, 34) and against the left posterolateral pericardium (point 14) induced a sensation of pressure and not of pain. The right lateral wall of the pericardium could not be properly tested for heavy pressure because of a confusing sensation of pain from contact of the instrument with the right edge of the wound. Pinching the edges of the incised pericardium with a tissue forceps produced much pain.

When the finger was introduced into the pericardial cavity and swept around the ventricles to detect walled-off pockets of pus at the time of operation, severe local pain resulted. The observations of Capps and of Simenauer with regard to pressure on the pericardium will be cited under the section "Observations by Others." Their observations and ours are at variance; the different conditions under which their and our observations were made may account for the disagreement.

Introduction of a catheter into the pericardial cavity toward the base of the heart both anteriorly (points 1, 19) and posteriorly (points 27, 34) caused moderately severe local pain. From ten days after operation, when the pericardium was thicker and presumably less sensitive, the pain was less severe and occasionally not present. As the pericardium shrank after drainage of its contained fluid, it became more difficult to introduce a catheter between the pericardium and the heart, and on several occasions when the catheter was left in place over the right ventricle for several minutes, the excursion of the ventricles between systole and diastole was seen to be lessened.

Several times when the pericardial cavity was being washed out by the installation of a surgical solution of chlorinated soda or a solution of mercurochrome through a catheter, the patient coughed up quantities of mucopurulent sputum—far more than at other times. He was not aware of any sensation, such as "tickling," as the stimulus to the urge to cough.

Pricking the lower anterior and diaphragmatic portions of the ventricles (points 5, 9, 12, 14, 16, 31, 32, 33) with the point of a needle to such a depth that a droplet of blood occasionally followed, was not felt in approximately half of the tests and in the others was felt only as touch, and the distinction between sharp and dull could not be made. Only at the apex of the heart (point 33) was every prick perceived as touch.

Many rapidly successive needle pricks of the diaphragm, about 1 cm. posterior to the level of the inner surfaces of the costal cartilages (points 22, 25) were only occasionally felt as local touch and never as pain.

At operation, piercing the cut edges of the incised pericardium caused sharp pain, and scratching its inner surface near to the incision with a needle caused slight pain.

The observations of Capps on piercing the pericardium and scratching its inner surface, and of Simenauer on pricking its outer surface, will be found under the section "Observations by Others."

At the time of operation the anterior surface of the left ventricle (points 12, 14) was grasped with two Allis forceps, 1 cm. apart, to the depth of about 1 mm., and the forceps were pulled away from one another with a force insufficient to tear the muscular fibers. This tension produced no local or referred anginal or anginoid pain.

Thermal sensation was tested by touching the heart, and the heart and pericardium simultaneously, with a thermometer that had been in hot and cold sterile

water. At the moment of removing the instrument from the warm water it registered between 130 and 140 F. in all tests, and cooled slightly before it could be applied to the patient. On removing it from the cool water it registered between 40 and 50 F. and became slightly warmer before it could be applied. The cool thermometer placed against the granulating cut edge of the pectoral muscle was identified as cold, but the warm thermometer as neither hot nor cold. Tests for sensation of heat and cold were made on the exposed anterior surface of both ventricles (points 6, 12) and of the diaphragm (point 24) and simultaneously on the adjacent surfaces of pericardium and right and left ventricles (points 3, 4, 17, 18). In no instance could the patient distinguish either heat or cold. The only sensation produced was of touch or pain, the latter probably being due to pressure by the thermometer.

*Subjective Interpretation of Stimuli.**

Stimulus	Epicardium and Ventricles	Diaphragmatic Pericardium	Parietal Pericardium
Light touch	0	0	—
Rubbing	Pressure	—	—
Heavy pressure	Touch	"A feeling" or pressure or slight pain	Posteriorly as pressure; anteriorly as pain, referred
Pinching	0	—	Severe pain
Finger or catheter in pericardial cavity	See parietal pericardium	—	Pain
Pricking	Occasionally as touch; constantly so at apex	Occasionally as touch	Sharp pain
Tension	0	—	—
Scratching	—	—	Slight pain
Heat	0	0	0
Cold	0	0	0
Vibration	0	0	—
Electricity	Pain with extrasystoles	—	—
Two points of pressure	Differentiated only when one point on each ventricle	Not differentiated	—

* The ciphers indicate that no sensation was produced and the dashes indicate that sensibility was not tested.

The temperature of the pericardial cavity was taken and is recorded, although unrelated to thermal sensation. An ordinary clinical thermometer was used and left in place five minutes or more. With the bulb of the thermometer near the right border of the sternum at about the fourth cartilage level (point 4), the temperature was 100.2 F. At the left border of the heart at the third interspace (point 18) and also beneath the right ventricle (point 28) the temperature was 100.7 F. At the time of this experiment the temperature by rectum was 101.3 F., by mouth 100.2 F. and by axilla 98 F.

Vibratory sensation was tested with tuning forks having 128 and 256 vibrations per second. These were placed directly on the anterior surfaces of both ventricles (points 5, 8, 12, 13) and on the diaphragmatic pericardium (points 24, 25). A sensation of vibration was nowhere perceived. When both the skin and the cut edge of the pectoral muscle were tested, the patient detected vibration when tuning fork 128 was used but not when fork 256 was employed, which produced only a sense of touch.

Electrical stimulation was effected by a Du Bois Raymond inductorium. With a key to deliver single make and break shocks we used a stimulating electrode

the points of which were about 3 mm. apart. The inductorium had 270 turns of wire on the primary coil and 5,000 turns on the secondary coil. We set the secondary coil to cover about three eighths of the primary coil. A single dry cell was used as a source of current.

Under these conditions the secondary coil delivered about 15 volts on the make shocks and 30 volts on the break shocks. It was found that such break shocks were approximately the ventricles' threshold for extrasystoles.

Such shocks were applied to points 3, 9, 14, 18 and 19 as well as to other points on the anterior surface of the right ventricle and to the base and apex of the left ventricle posteriorly; the exact position of these points will be fully given in our article devoted to consideration of the "Excitatory Process Observed in the Exposed Human Heart."[2]

Pain was produced on electrical stimulation when extrasystoles were produced. We cannot be certain, because of the difficulty of observing every extrasystole at the time the experiment was in progress, and before the electrocardiographic films were developed, that this was constantly so, nor that the pain did not sometimes occur when the heart was electrically stimulated without the production of extrasystoles.

At the time of operation, extrasystoles could not be produced by pricking, rubbing or pressing the heart.

In placing the blunt ends of two hemostats against the heart or diaphragmatic pericardium, care was taken that the parietal pericardium and thoracic wall were nowhere touched. Simultaneous pressure applied to points on the anterior surfaces of the right and left ventricles, 2 cm. apart (points 5, 13) and in another position at a distance of 2.5 cm. (points 10, 11) was repeatedly identified as two points of pressure. Pressure at two points on the right ventricle 2 cm. apart (points 7, 9) was identified as only one point. One point of pressure near the apex of the left ventricle (point 11) was repeatedly declared to be two points. Simultaneously applied pressure at two points 3 cm. apart on the diaphragmatic pericardium (points 24, 26) was not distinguished as two points. Single pressure elsewhere on the diaphragmatic pericardium (points 24, 26) was declared to be two points.

OBSERVATIONS BY OTHERS

Harvey[3] wrote of one of his patients whose heart lay exposed, except for a "layer of fungous flesh as in old ulcers," as a result of an old defect in the overlying thoracic wall. Both Harvey and his friend "his Serene Majesty King Charles" felt the heart and found it without sense of touch, as the patient did not know when it was touched except by sight, or sensation through the external integument. Harvey concluded that the heart itself appears to be insensitive. This opinion has been widely quoted.

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2. Barker, Paul S.; Macleod, A. Garrard; Alexander, John, and Wilson, Frank N.: The Excitatory Process Observed in the Exposed Human Heart: I. The Spread of Excitation as Determined by Direct Leads; II. The Electrical Responses of Induced Premature Ventricular Contractions, to be published in Tr. A. Am. Phys., 1929, and elsewhere.

3. Harvey, William: The Works of William Harvey, M.D., translated from the Latin by Robert Willis, M.D., London, printed for the Sydenham Society, 1847, pp. 382-384.

Luciani [4] stated that "the afferent fibers from the heart are incapable of conveying clear or conscious sensations." Souligoux [5] found that wounds of the heart are not in themselves painful and believed that the pain that occurs on the second or third day is due to inflammation of the pericardium or pleura. Lockwood [6] stated that in a case of a missile in the heart, when the heart and pericardium were handled the patient did not complain of pain or distress, either cardiac or respiratory, although only local anesthesia was used. Auchincloss [7] produced pain in the shoulder when he placed a clamp on the pericardium at its junction with the diaphragm. Cutler and Beck [8] found that the pericardium is sensitive, especially when inflamed, and Cutler [9] expressed the opinion that its upper and lateral portions are relatively much less sensitive than its lower portions.

Capps [10] produced no pain when the pericardium and heart were touched, pressed or scratched with a silver wire introduced into the pericardial cavity through a cannula in four patients with pericardial effusion. In two patients he "tripped" the apex of the heart with the wire. One of these complained of a "queer aching sensation like pressure" in the stimulated area; the other had an uncomfortable feeling over the heart, and "skipped beats," but no pain. No pain occurred in two cases when the pericardium was pierced with the trocar and cannula at the level of the fourth intercostal space near the midclavicular line, but there was definite pain in the region of the left trapezius muscle in two other cases when the pericardium was pierced at the level of the fifth and sixth interspaces. In cases of dry pericarditis with friction rub and in cases of pericardial effusion, Capps' patients had local sensations of oppression, tightness and dyspnea, but never pain unless there was pleural involvement. He concluded that pericarditis is a painless disease and that mechanical irritation of the serous

4. Luciani, Luigi: Human Physiology, translated from the Italian by Frances A. Welby, edited by Dr. M. Camis, London, MacMillan & Company, 1911, vol. 1, p. 335.

5. Souligoux, Charles: Affections chirurgicales de la poitrine, Paris, J. B. Baillière et fils, 1911, p. 106.

6. Lockwood, Ambrose L.: Surgery of the Pericardium and Heart, Arch. Surg. **18**:417 (Jan.) 1929.

7. Auchincloss, Hugh, in discussion on Peterson, Edward W.: Suppurative Pericarditis, Arch. Surg. **16**:377 (Jan.) 1928.

8. Cutler, Elliott C., and Beck, Claude: Surgery of the Heart and Pericardium, in Nelson's Loose-Leaf Living Surgery, New York, Thomas Nelson & Sons, 1927, vol. 4, chapt. 4.

9. Cutler, Elliott C.: Verbal communication, March 27, 1929.

10. Capps, Joseph A.: Pericardial Pain: An Experimental and Clinical Study, Arch. Int. Med. **40**:715 (Nov.) 1927.

pericardium causes no pain. Lord [11] remarked on the infrequency of pain in pericarditis.

Simenauer [12] tested the sensation of the outer or pleural surface of the pericardium by approaching it with a thoracoscope-cautery outfit in three patients under treatment with artificial pneumothorax. Touch, light and heavy pressure, and pricking were not felt, but very heavy pressure at the level of the sixth rib was felt as an unpleasant sensation. In one case pressure on the pericardium in the region of the apex of the heart caused a pain like that in angina pectoris and a sensation of pressure on the mesial surface of the upper left arm and in a part of the lower arm.

SUMMARY

1. The response of the human heart, parietal and diaphragmatic pericardium to various forms of directly applied stimuli, has been determined in a patient whose heart was exposed by pericardiostomy for suppurative pericarditis.

2. The ventricles were insensitive to light touch. Rubbing was interpreted as pressure. Heavy pressure and pricking with a needle were interpreted as touch. Tension on the left ventricular wall caused no pain. Heat from 130 to 140 F. and cold from 40 to 50 F. were not identified. Application of tuning forks with 128 and 256 vibrations per second did not produce a sensation of vibration. Electrical stimulation caused pain only when extrasystoles occurred. Two blunt points of pressure simultaneously applied from 2 to 3 cm. apart on the right and left ventricles were identified as two points. Two points of pressure on the right ventricle were constantly said to be one point and one point of pressure on the left ventricle, two points.

3. The diaphragmatic pericardium did not feel light touch. Heavy pressure was interpreted as "a feeling" or pressure, and once as slight pain. Heat, cold and vibration were not identified. Two points of simultaneous pressure, 3 cm. apart, were not distinguished as two, and on two occasions one point of pressure was said to be two.

4. The parietal pericardium had a sensation of pressure when pressure was applied to the inner surface of its posterior and left posteriolateral walls. When pressure was applied forward against the anterior pericardium and thoracic wall, there was severe local and referred pain. Pain was also produced by sweeping the finger around the pericardial cavity, by pinching, pricking and scratching the inner surface of the pericardium. Heat and cold were not identified.

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11. Lord, Frederick T., in discussion on Peterson, Edward W.: Suppurative Pericarditis, Arch. Surg. **16**:375 (Jan.) 1928.

12. Simenauer, Erich: Die Sensibilität von Pleuren, Pericard und Peritonealüberzug des Diaphragma und besonderer Berüchsichtigung des Nervus phrenicus, Ztschr. f. Tuberk. **48**:273, 1927.

5. With the exception of pressure against the anterior pericardium, none of the stimuli applied to the heart or pericardium caused distant reference of sensation to any part of the body.

6. The stimuli used to evoke sensory response produced only two reflexes that we detected. One was the "squirming" of the body and the extremities on painfully stimulating the heart or pericardium. These movements may have been wholly or partly voluntary. The other reflex was the activation of coughing on irrigating the pericardial cavity.

7. Our observations do not justify conclusions as to the nerve paths concerned in the sensations produced.

ABSTRACT OF DISCUSSION

DR. E. A. GRAHAM, St. Louis: I want to congratulate Dr. Churchill particularly for the excellent result obtained in his case. I think it is interesting that Dr. Churchill, Dr. Allen and I should be thinking about the same thing at about the same time.

In the cases which I presented and talked about yesterday, I doubt whether the procedure of removing a portion of the pericardium would have had any particular value, although possibly in the case of the boy who died there might have been some beneficial effect from removing part of his pericardium.

In the two fatal cases which were shown yesterday, however, the hearts were greatly enlarged. I am anxious to know whether there is much scar tissue in the parietal pericardium with supposedly resultant constriction, and whether one can expect to find clinical or x-ray evidence of a greatly enlarged heart when the parietal pericardium is thick. I have not any literature bearing on that point. I am wondering if perhaps Dr. Churchill has. At any rate, it is a splendid result, and I congratulate Dr. Churchill most heartily.

I think the important point in Dr. Churchill's case, together with any possible importance in the remarks I made yesterday, is to emphasize the fact that there must be literally hundreds of cases of this sort in which the patients are going around not getting relief and having their condition regularly diagnosed as chronic heart disease. These conditions are amenable to surgical measures, the simple procedure of removing a section of the wall of the chest and, in some cases, a portion of the pericardium.

DR. HOWARD LILIENTHAL, New York: About five years ago I operated on a patient with a calcified pericardium, who had all the symptoms which Dr. Churchill has mentioned in his paper.

My only reason for speaking, other than to congratulate Dr. Churchill on his operation, is to say that in the case in which I performed an operation the pericardium had practically turned to stone. It was nearly a third of an inch in thickness. It felt and looked like an ordinary plaster cast. The patient had a huge liver with great ascites. She was a woman in the early twenties. My approach at that time was one which I think I would use again, and which I would strongly recommend. It is the first and only time I have used it, but I am sure it has great advantages in cases of this kind. I refer to the Duval-Barasty incision. It is a thoracolaparotomy, an incision longitudinally dividing the gladiolus and xiphoid. With the sternum shears, the surgeon incises sagittally

nearly to the umbilicus. With a rib spreader in the edges of a wound of that kind, a magnificent exposure is afforded. It does not seem to be at all shocking to the patient. In my own case it was practically bloodless. In these cases in which the disease is due, not to adhesion of the wall of the chest, but to the compression of the heart itself, it has the advantage of preserving the wall of the chest intact.

I failed to cure my patient, for I was unable to cut through that tremendously thick, tough cast that was over the heart without, what I considered, grave danger. I did go through it for about an inch and a half and entered what I conceived to be the auricle. There was some bleeding which yielded to packing. The patient was relieved and was walking about a few days afterward, although she had a little infection in the wound. She was discharged from the hospital somewhat improved. She lived a number of years afterward and then died of the disease.

Dr. Alton Ochsner, New Orleans: There is just one point that I want to make with regard to the pathologic process and the technic.

I had the good fortune of serving as assistant to Schmieden in Frankfurt when he operated on three of these patients. The pathologic process is not only a fibrosis of the pericardium, but a marked fibrosis of the myocardium and epicardium. In two of these cases in which Schmieden performed an operation, it was impossible to tell when a part of the pericardium was removed. Frequently, the scalpel evidently went into the cardiac musculature.

I think Dr. Churchill is to be especially congratulated on the result he obtained. The results obtained in these cases are remarkable. They are all selected cases and, naturally, relatively few of them can be done; but I can agree with Dr. Churchill that in the selected cases the results are highly desirable and the operation should be done.

Dr. Elliott Carr Cutler, Cleveland: I have had two experiences with similar cases, and would like to congratulate Dr. Churchill on his brilliant success.

The great difficulty for all of us is going to be to choose the right procedure even when we have such cases referred to us. The correct procedure may not be clear until the lesion is exposed.

This (indicating on a slide) is a case of calcified pericardium, with symptoms exactly similar to those described by Dr. Churchill. This is the heart after removal, and after removal of the pericardium. The calcification in this case extended all through the heart muscle. The diaphragm, the apex of the heart and the pericardium were one solid piece of bony substance. All the material that we could remove in the region of the right ventricle was removed. But a knife and scissors were ineffective and rongeurs were resorted to.

Cases in this group will vary between this sort with a calcified pericardium, in which there is a lime and salt deposit around the coronary vessels, and cases of simple, adherent mediastinitis.

In the simple case in which the pericardium is adherent to the wall of the chest, when the intrapericardial adhesions are not so bad, the surgeon may do a great deal of good. During the past year, I unfortunately did a simple rib resection—the ordinary Brauer operation—on a patient suspected of having this condition. The patient benefited little by it and died six or eight months later. Autopsy showed that the patient should have had a Delorme operation. On the other hand, in certain cases the Delorme operation, or any sort of operation, is dangerous and probably foolhardy. Diagnosis must be improved.

I think the lesson to learn from this case is that there are a great many cases of disease of the pericardium that the physicians will not diagnose unless pushed

by the surgeons. Physicians will let such patients sit in bed, giving them digitalis for ten years without any hope of benefit, and not let the surgeon, who may offer possible hope, even examine the case in consultation.

Dr. Pol. N. Coryllos, New York: I want to congratulate Dr. Churchill for his remarkable presentation and to express my deepest respect to the internist who in this case asked the collaboration of the surgeon. The case reported by Dr. Churchill shows the feasibility of Delorme's operation in well selected cases. Unfortunately, the selection of these cases is a great diagnostic problem because the clinical diagnosis of adhesive pericarditis is extremely difficult. Over a hundred years ago, Corvisart, and more recently, Norris and Landis have stressed this point. The latter concluded that pericarditis is to be suspected if in an endocarditis of rheumatic origin the cardiac failure is more marked than the endocardiac damage seems to warrant.

Another diagnostic problem is the determination of the variety of the adhesive pericarditis. The adhesions may be limited to the two layers of the pericardium alone, and might produce an incomplete or even complete obliteration of the pericardial cavity. Or they may extend to the surrounding structures, mediastinum, lungs and wall of the chest, as in the adhesive mediastinopericarditis of Pick. In the first variety the heart is encased in a thick solid, unextensible, sometimes calcified sac, which limits its movements as a tightly fitting glove limits the movements of the hand, according to the expression of Cutler. In that variety there may be no adhesions to the thoracic wall and consequently absence of the three clinical signs characteristic of the disease, namely, systolic retraction, diastolic shock and fixation of the apex notwithstanding changes of position of the patient. The heart may be extremely hypertrophied, but it also may be small because of the inextensibility of the thickened pericardium.

In all these cases an imperative indication is present. The pressure exerted on the heart, and the additional work imposed on it because of the tightness of the adhesions and the rigidity of the structures pulled on should be relieved. I shall go even further and say that in every case of rheumatic heart, especially when it is greatly hypertrophied, on which digitalis has no effect, surgical intervention is indicated, provided that the infectious process is arrested and the patient has still sufficient vitality to withstand operation. This will be the Brauer operation. In the presence of parietopericardiac adhesions the heart will be greatly relieved. In cases of simple "cor bovinum" even without pericardiac adhesions the decompression of the heart will often have a gratifying effect, as Dr. Graham has insisted on. This operation, harmless by itself, may serve as the first stage of the ulterior Delorme operation as suggested by Cutler.

I had the opportunity to perform the operation of Brauer three times with such gratifying results that I wonder why this operation is not performed more often.

I feel convinced that when internists will be more familiar with the indications and the benefits of this procedure, and less reluctant to consult the thoracic surgeon in cases of cardiac disease, a new and interesting era of medicosurgical treatment in cardiac diseases will begin, following the path of the evolution of the treatment of pulmonary diseases. Delorme, Beck, von Schmieden, Cutler and Churchill have already shown the way by their pioneer work.

Dr. Edward D. Churchill, Boston: My apology for bringing a single case report before this society is that in so many aspects it forms an ideal or textbook picture of this unusual condition and its treatment. There are two important reasons why this particular patient was what may be called an ideal case. First, the myocardium was sound; and second, the left ventricle was not involved in

the scar. In addition, I did not have to deal with an extensive degree of calcification such as Dr. Cutler and Dr. Lilienthal described.

Again, I was fortunate in finding a good line of cleavage so that the pericardium came off like the skin of an orange. In a few places adhesions required sharp dissection, but it was practically bloodless except in one spot on the surface of the heart which required a silk stitch ligature. Schmieden had a case in which the adherent pericardium blended with the myocardium with such intimacy that he had to hold his knife blade parallel to the surface and cut the thickened scar away in slices.

I agree with Dr. Graham that it is highly questionable as to whether the pericardium should be resected when one is doing a decompression for an enlarged heart. In such a case one is dealing with a weakened myocardium in addition to other factors.

In regard to the sternum-splitting incision used by Dr. Lilienthal, I believe that it is excellently adapted for exploration of the pericardial cavity and for the valvulotomy of Dr. Cutler. The advantage of the approach which I have pictured is that it leaves the patient with a Brauer cardiolysis in addition to the actual pericardial resection. As the heart becomes adherent after the lysis of adhesions, a flexible precordial area may well prevent further difficulty.

OPERATIONS ON THE INNOMINATE ARTERY

REPORT OF A SUCCESSFUL LIGATION

JAMES GREENOUGH, M.D.
COOPERSTOWN, N. Y.

In July, 1923, a white woman, aged 45, was seen in the outpatient department of Bellevue Hospital with a throbbing swelling in the right side of her neck. There were hard nodules about this area, and she was referred to the Memorial Hospital for treatment for metastatic carcinoma. A specimen removed from the neck showed chronic inflammatory disease. She returned to the clinic and was admitted to the First Surgical division on Nov. 6, 1923, for observation.

She was complaining of severe pain. On examination she appeared to be rather old for her age, with considerable arteriosclerosis. She had a tremor of the hands and head, which was diagnosed paralysis agitans. The aneurysm in the neck was thought to be of the right common carotid artery. The Wassermann reaction was negative. In view of her general condition operation did not seem advisable, and she was discharged on November 27.

She was readmitted to the hospital on Sept. 16, 1924, because of an increase in pain. It radiated down her right arm and to her chest. The pain and dyspnea kept her awake at night. Examination revealed practically the same condition as before. The heart was normal in size, but there was a diastolic murmur over the aortic area and a systolic murmur at the apex. There was a thrill over the aneurysm. The right and left radial pulses were equal. There was some question as to the site of the aneurysm at this time, opinion being divided between aneurysm of the carotid and aneurysm of the subclavian arteries. As the pain seemed to be much more severe operation was decided on, and on September 20, with the patient under general anesthesia, I explored the neck and ligated the innominate, carotid and subclavian arteries.

There was a diffuse fusiform aneurysm of the upper part of the innominate artery and the first portion of the subclavian artery. The carotid was enlarged just at its origin.

An incision 6 inches (15.2 cm.) long was made ½ inch (1.3 cm.) above the right clavicle. This was deepened through platysma and fascia exposing the sternomastoid and clavicle. The sternomastoid was pulled laterally, and it was found that the aneurysmal mass was below the sternohyoid and sternothyroid and behind the clavicle. The clavicle was disarticulated from the sternum and turned laterally, exposing the retroclavicular tissues. The sternomastoid was cut at its insertion into the sternum, and the sternothyroid and sternohyoid were dissected away from the aneurysmal sac. The carotid, subclavian and innominate arteries were exposed in the bottom of the wound. It was found easy to surround the innominate artery without injuring the pleura. The carotid was distorted, being raised upward in the neck at its origin. The innominate artery was temporarily shut off and there was then felt no pulse in the right radial or right temporal arteries. However, at the end of five minutes there were still signs of circulation in the extremity, and it was deemed possible to ligate. Two ligatures of no. 2 chromic catgut, doubled, were passed around the innominate artery from within outward, and the innominate was ligated as close to the arch as could be reached without passing below the sternum. This was apparently proximal to the aneu-

rysmal dilatation. The carotid and subclavian arteries were ligated ½ inch beyond their origins with double ligatures of no. 2 chromic catgut. The clavicle was sewed to the sternum with interrupted chromic catgut sutures through the capsule and periosteum. The muscles were approximated over the arteries with interrupted chromic catgut sutures. The skin was closed with silkworm gut, without drainage.

The right arm was wrapped in absorbent cotton immediately after operation. There was no pulse in the radial artery. The right side of the face was somewhat cold.

On the first day after operation, pulsation was felt in the radial and brachial arteries. The face had become warmer and was the same color on the right as on the left. The next day, the wound was dressed. The clavicle was displaced upward somewhat. The wound was clean. There was no pulsation in the aneurysm, but a definite pulsation in the right radial artery.

On the third day, the edges of the wound were slightly red. Pulsation in the radial artery seemed the same. There was slight pulsation at the site of operation, and the patient complained of some pain in the arm. The sutures were removed on the fifth day. There was considerable inflammation about the wound. A culture was taken which grew *Staphylococcus aureus*. On the seventh day, there was a distinct superficial infection about the wound, and it gaped slightly. The edges of the skin were cleaned with green soap, alcohol and ether and approximated with adhesive tape. The patient complained of headache. There seemed to be no difference in the circulation in the two arms. On the eighth day, the wound was becoming cleaner. There was no definite pulsation in the right carotid artery. The patient seemed much better. On the eleventh day, the wound was opened at the inner angle and a brokendown blood clot drained out. The temperature had risen to 104 F. the night before, although previous to this it had been about 100 F. On the twelfth day, the temperature was normal. The sinus, which had closed, was reopened, and there was a moderate amount of discharge. There was slight pulsation in the neck and in the region of the scar. The temperature on this day rose to 102 F. On the thirteenth day, a drain was inserted, and there was still considerable drainage.

For the next week there was a moderate amount of discharge. The temperature rose to between 101 and 102 F. each night, but the patient's general condition improved. She was allowed up on the twentieth day after operation. On the twenty-sixth day, it was noted that the clavicle seemed to be firmly adherent. The arm could be used. There was no evidence of paralysis, and the wound was rapidly healing. On the thirty-first day, a probe was passed into the sinus and apparently grated on the end of the clavicle, which seemed to be infected.

The patient was discharged thirty-three days after operation. No circulatory disturbances had been noted. At the time of discharge, the paralysis agitans had not changed. There was still a sinus which communicated with the inner end of the clavicle. There was pulsation in the arm, but not as marked as on the other side. Systolic blood pressure in the right arm had dropped from 245 to 150.

The patient was readmitted to the hospital about one month later, on account of the discharge from the sinus, with a diagnosis of osteomyelitis of the inner end of the clavicle. On admission no radial pulse was felt, although the arm was normal in color and sensation. Motion of the arm was good. There was slight pulsation on the right side of the neck. There was a sinus at the medial end of the operative wound which extended down to the clavicle. Roentgen examination did not show the osteomyelitis.

On November 25, an incision was made over the right clavicle. The clavicle and sternum were separated by ½ inch and the medial end of the clavicle had ebonized. The sinus was enlarged, the medial end of the clavicle was removed with a chisel and rongeur and an oval opening was left 1 inch (2.5 cm.) in diameter, with firm granulating tissue at the bottom. The wound was packed with dichloramine-T. The sinus was dressed daily, but the lower part did not heal as there was apparently still a portion of bare bone at the end of the clavicle. The patient was discharged on Jan. 1, 1925.

She was readmitted to the hospital on February 19 with an increase in the tenderness about the sinus, which had never closed. She had been at a convalescent hospital. No carotid pulse could be felt, nor was there any pulsation over the clavicle. The right radial pulse was fainter than the left. Blood pressure observations, on February 20, showed in the right arm a pressure of 120 systolic and 100 diastolic and in the left 174 systolic and 104 diastolic. On February 26, the sinus was opened again. The granulations were soft and unhealthy. Another portion of the clavicle, 1.5 by 0.5 cm., had sequestrated and was removed. A portion of the bone over the sequestrum was removed, and an oval opening packed with iodoform gauze was left. Granulations gradually filled in and the patient was discharged to the City Hospital on April 6, with a small sinus. She was discharged from that hospital on April 17, 1925, and lost from observation. At that time there was a sinus still communicating with the inner end of the clavicle. The aneurysm was apparently healed as there was no mass and no pulsation. The pulse in the right radial artery was less than in the left and was absent in the right carotid. The use of the arm was interfered with by the osteomyelitis of the clavicle which had not healed.[1]

DATA FROM THE LITERATURE

Including my case, I have been able to find in the literature reports of 91 cases of operation on the innominate artery (table 1). They may be grouped as follows:

The innominate artery alone was ligated in 43 cases (table 2). These operations were performed for subclavian aneurysm in 26 cases, carotid aneurysm in 4, bifurcation aneurysm in 4, multiple aneurysm in 4, wounds in 4, and 1 case in which the diagnosis was unknown. There were 28 deaths and 15 recoveries, a mortality of 65 per cent. There were previous or subsequent ligations in 13 of the cases, or about 30 per cent. Of the 37 aneurysms, 10 are reported cured, 9 clotted and 3 improved. The aneurysm was thus definitely benefited in 59 per cent.

The innominate and carotid arteries were ligated in 20 cases (table 3). The operation was performed for subclavian aneurysm in 13 cases, bifurcation aneurysm in 2, multiple aneurysm in 2, innominate aneurysm in 1, stab wound in 1 and in 1 case in which the diagnosis was unknown. There were 9 deaths and 11 recoveries, a mortality of 45 per cent. There were previous or subsequent ligations in 6 of the cases, or 30 per cent. Of the 18 aneurysms, 6 were reported cured, 2 clotted and 4 improved. Thus 66 per cent of the aneurysms were benefited.

1. J. A. McCreery, Chief of the First Surgical Division, Bellevue Hospital, gave me permission to report this case.

TABLE 1.—*Data on Ninety-One Cases of Operation on the Innominate Artery*

Case	Surgeon	Date	Diagnosis	Operation	Result
1	V. Mott	1818	Subclavian aneurysm	Innominate ligation	Death
2	Graefe	1822	Subclavian aneurysm	Innominate ligation	Death
3	Norman	1824	Subclavian aneurysm	Innominate ligation	Death
4	Arendt	1827	Subclavian aneurysm	Innominate ligation	Death
5	Hall	1830	Subclavian aneurysm	Ligature through innominate	Death
6	W. H. Porter	1831	Subclavian aneurysm	Attempted innominate ligation	Recovery
7	Bland	1832	Subclavian aneurysm	Innominate ligation	Death
8	Bujalsky	1833	Subclavian aneurysm	Innominate ligation	Death
9	Unknown, reported by Dupuytren	1834	Unknown	Innominate ligation	Death
10	Kuhl	1836	Neoplasm of face	Subclavian and carotid ligation thought to be innominate	Death
11	Lizar	1837	Subclavian aneurysm	Innominate ligation	Death
12	Hoffman	1839	Subclavian aneurysm (2)	Attempted innominate ligation	Death
13	Hutin	1841	Axillary wound	Innominate ligation	Death
14	Key	1844	Innominate and subclavian aneurysm	Attempted innominate ligation	Death
15	Peixoto	1851	Tumor of ear	Precautionary innominate ligature, not tied	Recovery
16	Pirogoff	1852	Subclavian aneurysm	Innominate ligation	Death
17	Gore	1856	Subclavian aneurysm	Innominate ligation	Death
18	Cooper	1859	Subclavian and carotid aneurysm	Innominate ligation	Death
19	Cooper	1860	Subclavian aneurysm	Innominate ligation	Death
20	Smyth	1864	Subclavian aneurysm	Innominate and carotid ligation	Recovery
21	Lynch	1867	Wound	Innominate ligation	Death
22	G. H. Porter	1867	Subclavian aneurysm	Innominate acupressure 60 hours	Death
23	Bickersteth	1868	Subclavian aneurysm	Innominate ligation	Death
24	A. B. Mott	1868	Unknown	Innominate and carotid ligation	Death
25	Partridge	1870	Carotid aneurysm	Innominate ligation	Death
26	O'Grady	1873	Axillary and subclavian aneurysm	Innominate and carotid ligation	Death
27	Buchanan	1880	Subclavian aneurysm	Innominate ligation	Death
28	Thomson	1882	Subclavian aneurysm	Innominate ligation	Death
29	Banks	1883	Subclavian aneurysm	Innominate and carotid ligation	Death
30	Bull	1884	Subclavian aneurysm	Innominate, carotid and vertebral ligation	Death
31	Annandale	1885	Subclavian aneurysm	Pressure on innominate artery	Death
32	Helferich	1886	Subclavian aneurysm	Innominate, carotid and subclavian ligation	Death
33	May	1886	Subclavian aneurysm	Innominate ligation	Death
34	Durante	1887	Subclavian aneurysm	Innominate, carotid and vertebral ligation	Death
35	Lewtas	1889	Wound	Innominate ligation	Recovery
36	Twynam	1889	Subclavian aneurysm	Innominate and carotid ligation	Death
37	Jacobson	1890	Subclavian aneurysm	Innominate and carotid ligation	Death
38	Helferich	1890	Bifurcation aneurysm	Attempted innominate ligation	Death
39	Coppinger	1893	Subclavian aneurysm	Innominate and carotid ligation	Recovery
40	Hernandez	1894	Wound	Innominate ligation, carotid clamped	Recovery
41	Parham	1894	Bifurcation aneurysm	Attempted innominate ligation	Death
42	Symonds	1894	Subclavian aneurysm	Innominate and carotid ligation	Recovery
43	Burrell	1895	Subclavian aneurysm	Innominate ligation	Death
44	Harte	1896	Wound	Innominate, carotid, subclavian, jugular vein ligation	Death
45	Gay	1896	Subclavian aneurysm	Innominate ligation	Death
46	Schumpert	1898	Bifurcation aneurysm	Innominate ligation	Death
47	Moynihan	1898	Axillary and subclavian aneurysm	Innominate and carotid ligation	Death
48	Bennett	1898	Bifurcation aneurysm	Innominate ligation	Death
49	Curtis	1899	Subclavian aneurysm	Innominate ligation	Recovery
50	DeLaup	1900	Bifurcation and subclavian aneurysm	Innominate ligation	Death
51	von Ruediger	1901	Subclavian aneurysm	Innominate and subclavian ligation; sac partially excised	Death
52	Ballance	1902	Bifurcation aneurysm	Innominate and carotid ligation	Death

TABLE 1.—*Data on Ninety-One Cases of Operation on the Innominate Artery—Continued*

Case	Surgeon	Date	Diagnosis	Operation	Result
53	Persons	1904	Hemorrhage	Innominate ligation	Death
54	Sheen	1904	Subclavian aneurysm	Innominate and carotid ligation	Recovery
55	Saigo	1904	Traumatic carotid aneurysm	Innominate ligation	Recovery
56	Saigo	1905	Traumatic varicose subclavian aneurysm	Innominate ligation; innominate cut	Recovery
57	Halsted	1905	Subclavian aneurysm	Partial innominate ligation	Recovery
58	Cuneo	1905	Innominate and aortic aneurysm	Innominate ligation	Recovery
59	Curtis	1907	Subclavian aneurysm	Innominate ligation	Death
60	Halsted	1907	Bifurcation aneurysm	Innominate ligation	Recovery
61	Burns	1907	Subclavian aneurysm	Innominate ligation	Recovery
62	Myles	1908	Subclavian aneurysm	Innominate and carotid ligation; carotid cut	Death
63	Herzen	1908	Traumatic subclavian aneurysm	Innominate, carotid and subclavian arteries, subclavian and jugular vein ligated; carotid cut	Recovery
64	Kimura	1908	Bifurcation aneurysm	Innominate, carotid and subclavian ligation; all cut and sac excised	Recovery
65	Ballance	1909	Bifurcation aneurysm	Innominate ligation	Death
66	Sargent	1909	Innominate aneurysm	Innominate and carotid ligation	Recovery
67	Morf	1911	Subclavian aneurysm	Innominate and carotid ligation	Recovery
68	Ballance	1911	Subclavian aneurysm	Innominate ligation	Recovery
69	Morison	1912	Subclavian aneurysm	Innominate and carotid ligation	Recovery
70	Halsted	1912	Recurrent subclavian aneurysm	Innominate ligation	Recovery
71	Hamann	1913	Subclavian aneurysm	Innominate and carotid ligation	Recovery
72	Thompson	1914	Subclavian aneurysm	Innominate ligation	Death
73	Lessnoi	1915	Innominate and carotid aneurysm	Innominate ligation	Recovery
74	Hamann	1915	Subclavian aneurysm	Innominate and carotid ligation	Recovery
75	Hamann	1916	Bifurcation aneurysm	Innominate and carotid ligation	Death
76	Coughlin	1916	Subclavian aneurysm	Innominate and carotid ligation	Recovery
77	Sinclair	1916	Traumatic carotid aneurysm	Innominate ligation	Recovery
78	Coughlin	1916	Unknown	Attempt to ligate innominate	Death
79	Makins	War	Gun shot wound, subclavian	Innominate clamped temporarily, subclavian ligation	Death
80	Makins	War	Traumatic subclavian varicose aneurysm	Innominate, subclavian artery and subclavian vein ligation, sac excised	Recovery
81	Sauerbruch	War	Gun shot wound, innominate	Suture of innominate	Death
82	Halsted	1918	Carotid aneurysm	Innominate ligation	Recovery
83	Reid	1918	Innominate aneurysm	Attempt to ligate innominate	Death
84	Halsted	1918	Gun shot wound, innominate	Suture of innominate	Recovery
85	Ballance	1918	Subclavian aneurysm	Innominate ligation	Recovery
86	Juckelson	1919	Carotid aneurysm	Innominate, carotid, subclavian ligation; sac partly excised	Recovery
87	Hertzler	1922	Traumatic subclavian aneurysm	Innominate ligation	Recovery
88	Holman	1922	Traumatic, subclavian aneurysm, varicose	Innominate, subclavian artery and vein and sac sutured	Recovery
89	Greenough	1924	Bifurcation aneurysm	Innominate, carotid and subclavian ligation	Recovery
90	Sauerbruch	1925	Tumor thyroid; rupture of innominate	Innominate suture	Recovery
91	Flint	1927	Traumatic bifurcation aneurysm	Innominate ligation and subclavian suture; sac packed	Recovery

TABLE 2.—*Innominate Ligations*

No.	Diagnosis	Result	Date	Other Ligations	Aneurysm
1	Subclavian aneurysm	Death	25th day		
2	Subclavian aneurysm	Death	67th day	.....	Infected
3	Subclavian aneurysm	Death	5th day		
4	Subclavian aneurysm	Death	8th day		
7	Subclavian aneurysm	Death	18th day	.....	Temporary improvement
8	Subclavian aneurysm	Death	5th day		
9	Unknown	Death			
11	Subclavian aneurysm	Death	21st day	.....	Clotted
13	Wound	Death	12th hour	Subclavian	
16	Subclavian aneurysm	Death	2d day	.....	Improved
17	Subclavian aneurysm	Death	16th day	.....	Clotted
18	Carotid and subclavian aneurysm	Death	9th day		
19	Subclavian aneurysm	Death	41st day	.....	Clotted
21	Wound	Death	12th day	Carotid	
23	Subclavian aneurysm	Death	6th day	Innominate pressure	Clotted
25	Carotid aneurysm	Death	1½ hours	Carotid	
27	Subclavian aneurysm	Death			
28	Subclavian aneurysm	Death	40th day	.....	Clotted
33	Subclavian aneurysm	Death	18th day	.....	Partly clotted
35	Wound	Recovery	43d day		
43	Subclavian aneurysm	Death	104th day	.....	Clotted
45	Subclavian aneurysm	Death	41st day	Carotid	
46	Bifurcation aneurysm	Death	9th day		
48	Bifurcation aneurysm	Death	3d day		
49	Subclavian aneurysm	Recovery	11 months	Carotid and subclavian	Cured
50	Subclavian and bifurcation aneurysm	Death	18th day	Carotid and vertebral	Clotted
53	Wound	Death			
55	Traumatic carotid aneurysm	Recovery	9 months	Carotid	Cured
56	Traumatic varicose subclavian aneurysm	Recovery	7 months	Subclavian artery and vein; excision of sac	Cured
57	Traumatic varicose subclavian aneurysm	Recovery	15 years	.....	Cured
58	Aortic and innominate aneurysm	Recovery	5 years	.....	Improved
59	Subclavian aneurysm	Death	4th day	.....	Clotted
60	Bifurcation aneurysm	Recovery death	..... 11 months	Carotid	Cured
61	Subclavian aneurysm	Recovery	21st day		
65	Bifurcation aneurysm	Death	30 hours		
68	Subclavian aneurysm	Recovery	1 month	.....	Cured
70	Subclavian aneurysm	Recovery	47th day	Subclavian	Improved
72	Subclavian aneurysm	Death	67th day	.....	Clotted
73	Innominate and carotid aneurysm	Recovery	.....	.....	Cured
77	Traumatic carotid	Recovery	8 months	.....	Cured
82	Carotid aneurysm	Recovery	6 years	Carotid	Cured
85	Subclavian aneurysm	Recovery death	..... 2 years	.....	Cured
87	Subclavian aneurysm	Recovery	7 months	Carotid and vertebral	Unchanged

TABLE 3.—*Innominate and Carotid Ligations*

No.	Diagnosis	Result	Date	Other Ligations	Aneurysm
20	Subclavian aneurysm	Recovery death	..... 17 months	Vertebral	Improved; recurred
24	Unknown	Death	23d day	.....	Ruptured
26	Subclavian and axillary aneurysm	Death	15 hours		
29	Subclavian aneurysm	Death	104th day	Subclavian	Improved
36	Subclavian aneurysm	Death	18 hours	.....	Clotted
37	Subclavian aneurysm	Death	10th day	.....	Clotted
39	Subclavian aneurysm	Recovery	2½ years	.....	Cured
40	Wound	Recovery	6 years		
42	Subclavian aneurysm	Recovery death	5 years	.....	Cured
47	Subclavian (2) and axillary aneurysm	Death	1 hour	Subclavian and axillary	Second ruptured
52	Bifurcation aneurysm	Death	1½ days		
54	Subclavian aneurysm	Recovery	9 months	Subclavian	Cured
62	Subclavian aneurysm	Death	1 month	Carotid	
66	Innominate aneurysm	Recovery death	..... 17 months	.....	Cured
67	Subclavian aneurysm	Recovery	6 years	.....	Improved
69	Subclavian aneurysm	Recovery	2 years	.....	Improved
71	Subclavian aneurysm	Recovery	13 months	.....	Cured
74	Subclavian aneurysm	Recovery	2 months	.....	Improved
75	Bifurcation aneurysm	Death	4 days		
76	Subclavian aneurysm	Recovery	2 years	Partial innominate	Cured

The innominate, carotid and subclavian arteries were ligated with or without associated veins in 6 cases (table 4). This was done for subclavian aneurysm twice, bifurcation aneurysm twice, carotid aneurysm once and gunshot wound once. Four patients recovered and 2 died, a mortality of 33 per cent. There was previous ligation in 1, or 16.66 per cent, of the cases. Of the 5 aneurysms, 4 were cured, or 80 per cent.

The innominate and subclavian arteries were ligated in 4 cases with or without associated veins (table 5). Three ligations were performed for subclavian aneurysm and 1 for bifurcation aneurysm. There was

TABLE 4.—*Innominate, Carotid and Subclavian Ligations*

No.	Diagnosis	Result	Date	Other Ligations	Aneurysm
32	Subclavian aneurysm.....	Death	2d day		
44	Wound.....	Death	Hour	Carotid	
63	Subclavian aneurysm.....	Recovery	4 months	.....	Cured
64	Bifurcation aneurysm.....	Recovery	.....	.....	Cured
86	Carotid aneurysm.....	Recovery	6 years	.....	Cured
89	Bifurcation aneurysm.....	Recovery	19 months	.....	Cured

TABLE 5.—*Innominate and Subclavian Ligations*

No.	Diagnosis	Result	Date	Other Ligations	Aneurysm
51	Subclavian aneurysm.....	Death	Hour		
80	Traumatic varicose subclavian aneurysm	Recovery	12th day	.....	Cured
88	Traumatic varicose subclavian aneurysm	Recovery	1 year	.....	Cured
91	Bifurcation aneurysm.....	Recovery	6 months	.....	Cured

TABLE 6.—*Innominate, Carotid and Vertebral Ligations*

No.	Diagnosis	Result	Date	Other Ligations	Aneurysm
30	Subclavian aneurysm.....	Death	33d day	.....	Infected
34	Subclavian aneurysm.....	Death	16th day		

1 death, a mortality of 25 per cent. There were no previous or subsequent ligations, and the aneurysm was cured in 3 cases, or 75 per cent.

The innominate, carotid and vertebral arteries were ligated for subclavian aneurysm in 2 cases (table 6). Both patients died with no benefit to the aneurysm, a mortality of 100 per cent. There were no previous or subsequent ligations.

Figure 1 shows a comparison of the mortality, the benefit to the aneurysm and the associated operations in these various groups.

Unsuccessful attempts to ligate the innominate artery were made 9 times. Temporary pressure was applied 4 times. The vessel was sutured 3 times.

The causes for operation were aneurysm, 75; injury, 9; hemorrhage from remote pathologic process, 3, and in 4 the cause was not given.

The 75 aneurysms were grouped as follows: subclavian, 50; bifurcation, 9; carotid, 6; innominate, 2; multiple, 8; involving the subclavian, 6 times; innominate, 3; carotid and axillary, 2 each; bifurcation and aorta, 1 each.

The total mortality for the series is 59.3 per cent. For purposes of discussion, I have divided the series into three groups. Table 7 shows the cases that occurred previous to 1880, or in the preaseptic period. There were 27 cases with 3 recoveries, a mortality of 89 per cent. Table 8 shows the cases that occurred from 1880 to an arbitrary point in 1904, when the mortality rate suddenly began to drop. There

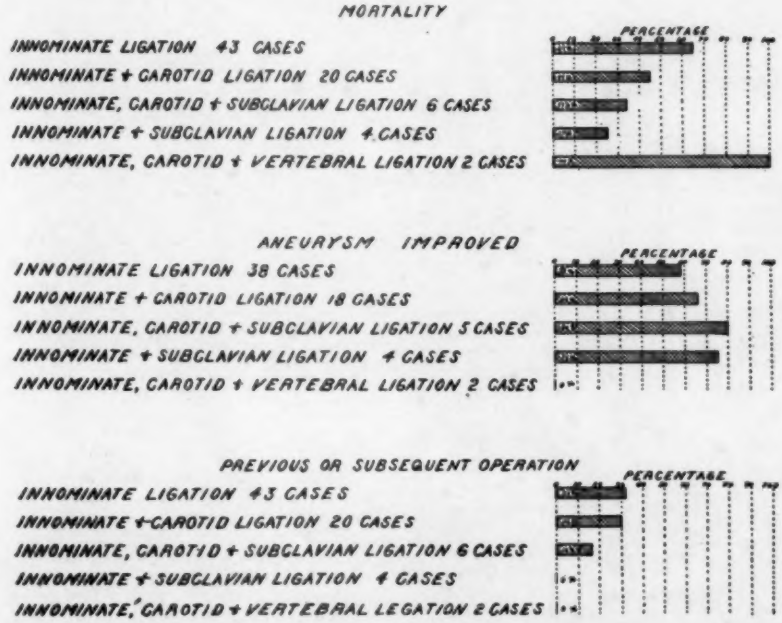
MORTALITY
PERCENTAGE
INNOMINATE LIGATION 43 CASES
INNOMINATE + CAROTID LIGATION 20 CASES
INNOMINATE, CAROTID + SUBCLAVIAN LIGATION 6 CASES
INNOMINATE + SUBCLAVIAN LIGATION 4 CASES
INNOMINATE, CAROTID + VERTEBRAL LIGATION 2 CASES
ANEURYSM IMPROVED
PERCENTAGE
INNOMINATE LIGATION 38 CASES
INNOMINATE + CAROTID LIGATION 18 CASES
INNOMINATE, CAROTID + SUBCLAVIAN LIGATION 5 CASES
INNOMINATE + SUBCLAVIAN LIGATION 4 CASES
INNOMINATE, CAROTID + VERTEBRAL LIGATION 2 CASES
PREVIOUS OR SUBSEQUENT OPERATION
PERCENTAGE
INNOMINATE LIGATION 43 CASES
INNOMINATE + CAROTID LIGATION 20 CASES
INNOMINATE, CAROTID + SUBCLAVIAN LIGATION 6 CASES
INNOMINATE + SUBCLAVIAN LIGATION 4 CASES
INNOMINATE, CAROTID + VERTEBRAL LEGATION 2 CASES

Fig. 1.—Graphs showing mortality, improvement and additional operations in ligations of the innominate artery and its branches.

were 26 cases with 5 recoveries, a mortality of 81 per cent. Table 9 shows the 38 cases that occurred from 1904 to date in which there were 29 recoveries, a mortality of 24 per cent. Figure 2 shows the mortality by tens from the beginning. This also demonstrates the sharp drop in the mortality rate about 1904.

Examination of the causes of death may show the reason for this change. Table 10 gives the causes of the 54 deaths as follows: suppuration, suppuration and hemorrhage, or hemorrhage, 30, or 56 per cent; shock, 11, and cerebral lesions, 7. Thus 48, or 89 per cent, are definitely due to causes arising from the operation itself. Infection is

the primary cause for hemorrhage. Fifty-six per cent of the deaths can be traced to infection then. If this is the case, there must be some factors in addition to asepsis which account for the drop in the mortality rate because it does not occur in 1880 with the introduction of asepsis but almost twenty-five years later, in 1904.

I believe that the improvement is due to greater facility in operating, as shown by the development of the operative exposure, the improvement in ligature material and application of the ligature, and to closure of the wound without drainage.

The incision advocated by Mott, who performed the first ligation in 1818, was a V type with one limb along the border of the sternomastoid

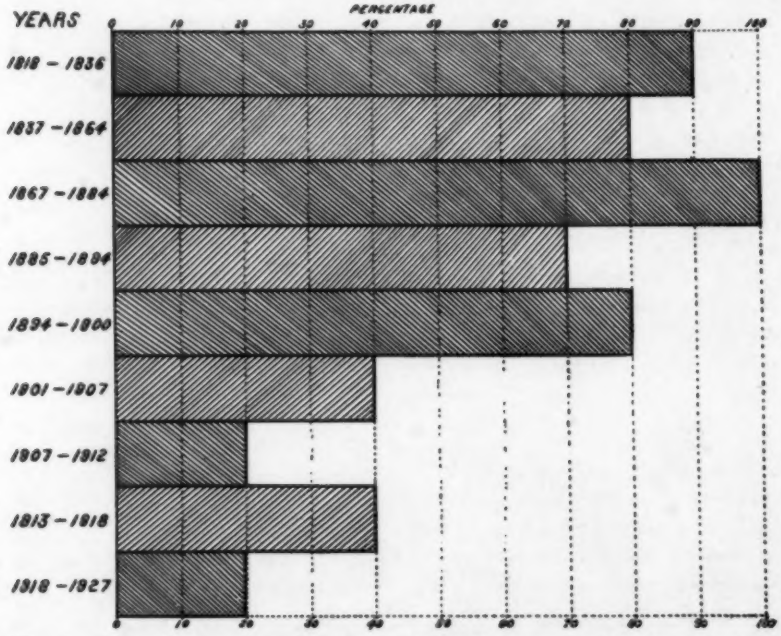

Fig. 2.—Mortality in operations on the innominate artery in groups of ten.

muscle, the other above the clavicle. This has been described with slight modification in 27 cases. A single incision in the midline along the sternomastoid or along the clavicle has been used 28 times. Various other types of right angle incisions making flaps to be drawn back in various ways have been used occasionally (fig. 3).

Of more interest, however, is the gradual development of bone resection in addition to the soft part dissection (fig. 4). In 1859, Cooper, who performed the eighteenth ligation of the series, first removed part of the bony thoracic wall. He resected parts of the manubrium and the right clavicle. This gave a better exposure and made the operation simpler.

In the 27 cases that occurred before 1880, when the mortality was 89 per cent, there were 3 bone resections. In the 26 cases that occurred from 1880 to 1904, when the mortality was 81 per cent, there were 11

TABLE 7.—*Cases from 1818 to 1880*

No.	Surgeon	Date	Ligation	Result
1	V. Mott	1818	Innominate	Death
2	Graefe	1822	Innominate	Death
3	Norman	1824	Innominate	Death
4	Arendt	1827	Innominate	Death
5	Hall	1830	Needle through innominate	Death
6	W. H. Porter	1831	Attempted innominate	Recovery
7	Bland	1832	Innominate	Death
8	Bujalsky	1833	Innominate	Death
9	Unknown	1834	Innominate	Death
10	Kuhl	1836	Attempted innominate	Death
11	Lizar	1837	Innominate	Death
12	Hoffman	1839	Attempted innominate	Death
13	Hutin	1841	Innominate	Death
14	Key	1844	Attempted innominate	Death
15	Peixoto	1851	Precautionary innominate	Recovery
16	Pirogoff	1852	Innominate	Death
17	Gore	1856	Innominate	Death
18	Cooper	1859	Innominate	Death
19	Cooper	1860	Innominate	Death
20	Smyth	1864	Innominate and carotid	Recovery
21	Lynch	1867	Innominate	Death
22	G. H. Porter	1867	Pressure on innominate	Death
23	Bickersteth	1868	Innominate	Death
24	A. B. Mott	1868	Innominate and carotid	Death
25	Partridge	1870	Innominate	Death
26	O'Grady	1873	Innominate and carotid	Death
27	Buchanan	1880	Innominate	Death

Cases, 27; deaths, 24; mortality, 89 per cent

TABLE 8.—*Cases from 1882 to 1904*

No.	Surgeon	Date	Ligation	Result
28	Thomson	1882	Innominate	Death
29	Banks	1883	Innominate and carotid	Death
30	Bull	1884	Innominate, carotid and vertebral	Death
31	Annandale	1885	Pressure on innominate	Death
32	Helferich	1886	Innominate, carotid and subclavian	Death
33	May	1886	Innominate	Death
34	Durante	1887	Innominate, carotid and vertebral	Death
35	Lewtas	1889	Innominate	Recovery
36	Twynam	1889	Innominate and carotid	Death
37	Jacobson	1890	Innominate and carotid	Death
38	Helferich	1890	Attempted innominate	Death
39	Coppinger	1893	Innominate and carotid	Recovery
40	Hernandez	1894	Innominate and carotid	Recovery
41	Parham	1894	Attempted innominate	Death
42	Symonds	1894	Innominate and carotid	Recovery
43	Burrell	1895	Innominate	Death
44	Harte	1896	Innominate, carotid, subclavian and jugular vein	Death
45	Gay	1896	Innominate	Death
46	Schumpert	1898	Innominate	Death
47	Moynihan	1898	Innominate and carotid	Death
48	Bennett	1898	Innominate	Death
49	Curtis	1899	Innominate	Recovery
50	DeLaup	1900	Innominate	Death
51	von Ruediger	1901	Innominate and subclavian	Death
52	Ballance	1902	Innominate and carotid	Death
53	Persons	1904	Innominate	Death

Cases, 26; deaths, 21; mortality, 81 per cent

bone resections. In the 38 cases that occurred since 1904, when the mortality was 24 per cent, there were 23 bone resections. In the 37 cases in which bone resection was done there were 17 deaths, or a mortality of 46 per cent. In the 54 cases in which bone resection was

not performed or is not mentioned, there were 37 deaths, or a mortality of 68.5 per cent.

Except when the bifurcation is high, the work on the vessels has to be done by palpation when the thoracic bony wall is not resected. As evidence of this I have found in the cases in which ligations were attempted, without bone resection, 2 cases in which the innominate could not be dissected out, 1 in which the carotid and the subclavian were tied together by mistake for the innominate, 1 in which the

TABLE 9.—*Cases from 1904 to 1927*

No.	Surgeon	Date	Ligation	Result
54	Sheen	1904	Innominate and carotid	Recovery
55	Saigo	1904	Innominate	Recovery
56	Saigo	1905	Innominate and cut	Recovery
57	Halsted	1905	Partial innomintae	Recovery
58	Cuneo	1905	Innominate	Recovery
59	Curtis	1907	Innominate	Death
60	Halsted	1907	Innominate	Recovery
61	Burns	1907	Innominate	Recovery
62	Myles	1908	Innominate and carotid	Death
63	Herzen	1908	Innominate, carotid, subclavian and subclavian vein	Recovery
64	Kimura	1908	Innominate, carotid and subclavian	Recovery
65	Ballance	1909	Innominate	Death
66	Sargent	1909	Innominate and carotid	Recovery
67	Morf	1911	Innominate and carotid	Recovery
68	Ballance	1911	Innominate	Recovery
69	Morison	1912	Innominate and carotid	Recovery
70	Halsted	1912	Innominate	Recovery
71	Hamann	1913	Innominate and carotid	Recovery
72	Thompson	1914	Innominate	Death
73	Lessnoi	1915	Innominate	Recovery
74	Hamann	1915	Innominate and carotid	Recovery
75	Hamann	1916	Innominate and carotid	Death
76	Coughlin	1916	Innominate and carotid	Recovery
77	Sinclair	1916	Innominate	Recovery
78	Coughlin	1916	Attempted innominate	Death
79	Makins	War	Innominate clamped, subclavian ligated	Death
80	Makins	War	Innominate, subclavian and subclavian vein	Recovery
81	Sauerbruch	War	Innominate suture	Death
82	Halsted	1918	Innominate	Recovery
83	Reid	1918	Attempted innominate	Death
84	Halsted	1918	Innominate suture	Recovery
85	Ballance	1918	Innominate	Recovery
86	Juckelson	1919	Innominate, cartoid and subclavian	Recovery
87	Hertzler	1922	Innominate	Recovery
88	Holman	1922	Innominate, subclavian and subclavian vein	Recovery
89	Greenough	1924	Innominate, carotid and subclavian	Recovery
90	Sauerbruch	1925	Innominate suture	Recovery
91	Flint	1927	Innominate and subclavian	Recovery

Cases, 38; deaths, 9; mortality, 24 per cent

aneurysm needle was passed through the innominate artery, and 1 in which the patient died from the shock of pulling on the aorta.

When the clavicle and sternum, with or without the first rib, are partially resected, the patients show practically no disability. Fibrous union develops which is sufficient for the function of the arm. The operation of ligation, whether for aneurysm or vascular injury, is undertaken as a life-saving measure. The advantages of exposure certainly outweigh the disadvantages of slight disability due to bone resection.

In my own case I dislocated the sternal end of the clavicle. The infection and nonunion following this procedure detracted from the

TABLE 10.—*Deaths Occurring Following Ligations*

No.	Diagnosis	First Ligation	Second Ligation	Date	Cause of Death
1	Subclavian aneurysm	Innominate	.. ..	25th day	Suppuration and hemorrhage
2	Subclavian aneurysm	Innominate	.....	67th day	Suppuration and hemorrhage
3	Subclavian aneurysm	Innominate	.....	5th day	Pericarditis
4	Subclavian aneurysm	Innominate	.....	8th day	Suppuration, pneumonia, cerebral lesion
5	Subclavian aneurysm	Attempted innominate	.....	5th day	Suppuration and pericarditis
7	Subclavian aneurysm	Innominate	.....	18th day	Suppuration and hemorrhage
8	Subclavian aneurysm	Innominate	.....	5th day	Suppuration, pericarditis, empyema
9	Subclavian aneurysm	Innominate	.....	.....	Hemorrhage
10	Neoplasm.....	Attempted innominate	.....	3d day	
11	Subclavian aneurysm	Innominate	.....	21st day	Internal and external hemorrhage
12	Subclavian aneurysm	Attempted innominate	.....	85th day	Exhaustion
13	Wound.....	Subclavian	Innominate	12 hours	Shock
14	Innominate, subclavian aneurysm	Attempted innominate	.....	25th day	Pressure on trachea
16	Subclavian aneurysm	Innominate	....	2d day	Suppuration, pneumonia, meningitis
17	Subclavian aneurysm	Innominate	.....	16th day	Suppuration and hemorrhage
18	Subclavian and carotid aneurysm	Innominate	.....	9th day	Suppuration and nephritis
19	Subclavian aneurysm	Innominate	.....	41st day	Suppuration and hemorrhage
21	Wound.....	Carotid	Innominate	12th day	Hemorrhage
22	Subclavian aneurysm	Innominate pressure	.....	10th day	Hemorrhage
23	Subclavian aneurysm	Innominate pressure	Innominate	6th day	Hemorrhage
24	.....	Innominate and carotid	.....	23d day	Aneurysm ruptured, hemorrhage
25	Carotid aneurysm....	Carotid	Innominate	1½ hours	Shock
26	Subclavian aneurysm	Innominate and carotid	.....	15 hours	Cerebral effusion
27	Subclavian aneurysm	Innominate	.....	.....	Shock
28	Subclavian aneurysm	Innominate	.....	40th day	Suppuration and hemorrhage
29	Subclavian aneurysm	Innominate and carotid	Subclavian	104th day	Suppuration and hemorrhage, 2d operation
30	Subclavian aneurysm	Innominate, carotid, subclavian	.....	33d day	Hemorrhage
31	Subclavian aneurysm	Innominate pressure	.. ..	17th day	Hemorrhage
32	Subclavian aneurysm	Innominate, carotid, subclavian	.....	2d day	Cerebral embolus and thrombosis
33	Subclavian aneurysm	Innominate	.....	18th day	Suppuration and hemorrhage
34	Subclavian aneurysm	Innominate, carotid, vertebral	....	16th day	Left cerebral embolus
36	Subclavian aneurysm	Innominate and carotid	....	18 hours	Cerebral thrombosis
37	Subclavian aneurysm	Innominate and carotid	.....	10th day	Suppuration and bronchopneumonia
38	Subclavian aneurysm	Attempted innominate	.....	16th day	Suppuration and hemorrhage
41	Bifurcation.....	Attempted innominate	.....	17 hours	Shock
43	Subclavian aneurysm	Innominate	.....	104th day	Cardiac failure
44	Wound.....	Carotid	Innominate, carotid, subclavian	Hour	Shock
45	Subclavian aneurysm	Innominate	Carotid	41st day	Suppuration and hemorrhage
46	Carotid aneurysm....	Innominate	.....	9th day	Cerebral lesion
47	Subclavian.....	Subclavian	Innominate and carotid	1 hour	Shock, rupture, second aneurysm
48	Bifurcation aneurysm	Innominate	.....	3d day	Hemorrhage
50	Bifurcation aneurysm	Innominate	Carotid and vertebral	18th day	Shock of second operation
51	Subclavian aneurysm	Innominate and subclavian	.....	Hour	Shock

beneficial result on the aneurysm. I have regretted that owing to lack of experience I used this procedure for exposure rather than resection.

Silk or hemp was the original ligature material. From 1880 to 1900 many experiments were being conducted on ligature material. One reads of the advantages and disadvantages of absorbable and non-absorbable materials, or of the various substances in each class. Ox aorta, ox peritoneum or gold beater's skin, kangaroo tendon, carbolized catgut, chromic catgut, horse hair, silver wire and many other substances were used. Ballance and Edmunds, in an exhaustive study on ligations, came to the conclusion that an aseptic ligature which remained sufficiently long to cause permanent occlusion was the best. Heavy

TABLE 10.—*Deaths Occurring Following Ligations—Continued*

No.	Diagnosis	First Ligation	Second Ligation	Date	Cause of Death
52	Bifurcation aneurysm	Innominate and carotid	.....	36 hours	Hemiplegia, carotid, thrombosis
53	Wound.....	Innominate			
59	Subclavian aneurysm	Innominate	.....	4th day	Bronchopneumonia
62	Subclavian aneurysm	Innominate and carotid	Carotid	1 month	Suppuration and hemorrhage, 2d operation
65	Bifurcation aneurysm	Innominate	.....	30 hours	Shock
72	Subclavian aneurysm	Innominate	.....	67th day	Suppuration and hemorrhage
75	Bifurcation aneurysm	Innominate and carotid	.....	4th day	Hemiplegia
78	.....	Attempted innominate	.....	.....	Innominate rupture, hemorrhage
79	Wound.....	Innominate pressure; subclavian	.....	3 hours	Shock
81	Wound.....	Innominate suture	.....	5th day	Mediastinitis
83	Innominate aneurysm	Attempted innominate	.....	.....	Shock

SUMMARY

Suppuration and hemorrhage	12
Shock	11
Hemorrhage	10
Suppuration and other conditions	8
Cerebral lesion	7
Miscellaneous	4
Unknown	2

skill, kangaroo tendon and modern chromicized gut fill these conditions and the latter is now provided with so little variation that it has become the ligature of choice.

These authors also showed that a force sufficient to occlude without rupture insured the best results. They advise for this a force of between 3 and 10 pounds, for the innominate artery, and a knot which they devised and which they called the stay knot (fig. 5). Two ligatures are placed side by side and the first knot tied independently but with the strands parallel throughout. The second knot is tied with both strands together in such a way as to form a square knot for each strand. The advantage of this procedure is that the friction between the two strands prevents slipping while tying the second knot. This makes it possible to apply the correct force to the first knot and to have it remain con-

stant. When the coats are crushed there is devitalized tissue which is accepted in modern theory to be favorable to infection. When infection starts at the site of ligation, the picture of ulceration of the vessel and hemorrhage is almost constant.

Drainage was constant in the preaseptic period and is mentioned in 8 of 10 cases in the period from 1880 to 1900, and in 9 of 15 cases

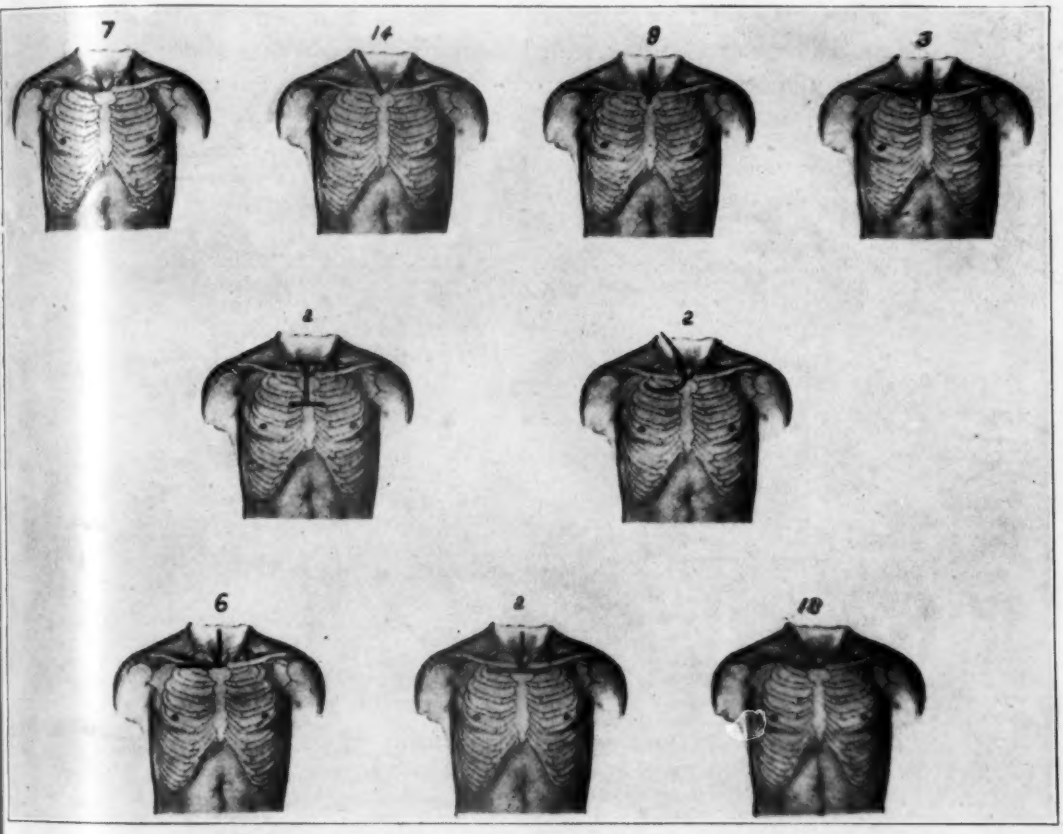

Fig. 3.—Diagram of incisions used in operations on the innominate artery. The figures show the number of times each type of incision was used.

since 1900. Surgeons are gradually draining fewer and fewer operative wounds and are profiting by the decrease in infection.

The advisability of associated ligation of other vessels is difficult to work out from the statistics of this series. In most of the cases before asepsis, the innominate alone was ligated. Whether the improvement since then can be attributed to more extensive ligation is difficult to say.

Figure 1 shows that the mortality in ligations of the innominate artery is 65 per cent; of the innominate and carotid, 45 per cent; of the innominate, carotid and subclavian, 33 per cent; of the innominate and subclavian, 25 per cent, and of the innominate, carotid and vertebral, 100 per cent; also that previous or subsequent ligations were done respectively in the innominate in 30 per cent; the innominate and carotid, 30 per cent; the innominate, carotid and subclavian, 16.66 per cent; the innominate and subclavian, 0 per cent, and in the innominate, carotid and vertebral, 0 per cent. The aneurysm was benefited respectively in the innominate, 58 per cent; the innominate and carotid, 66 per cent; the innominate, carotid and subclavian, 80 per cent; the

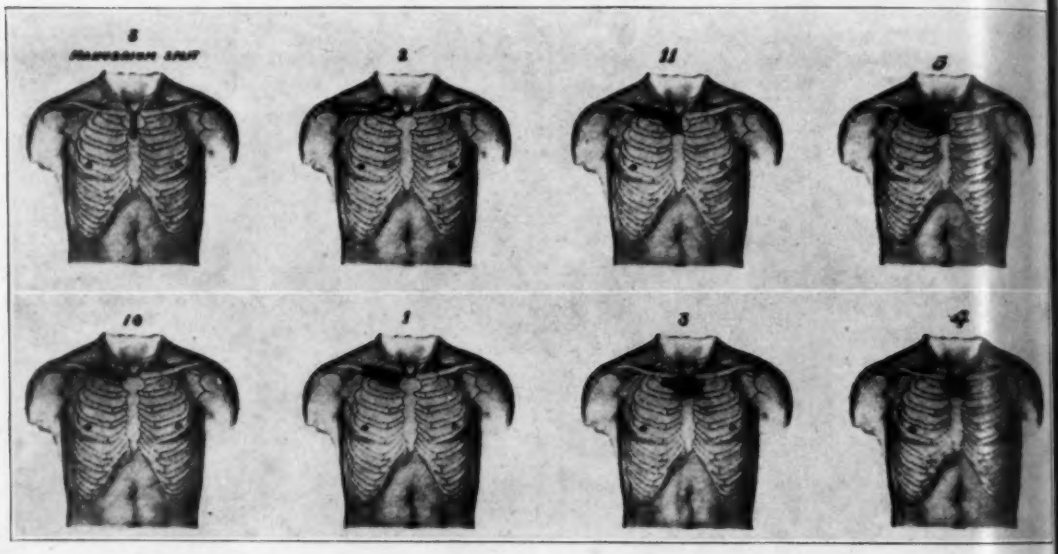

Fig. 4.—Diagram of bone resection in operations on the innominate artery. The figures show the number of times each type of bone resection was done.

innominate and subclavian, 75 per cent; the innominate, carotid and vertebral, 0 per cent. These figures would indicate that multiple ligation is advisable; that combinations including the subclavian are better than those including the carotid, and that the vertebral should not be included.

It has been argued that the carotid should be ligated with the innominate, as the collateral for the subclavian is largely retrograde from the brain to the arm. The 7 cases of cerebral lesion occurring in the series do not seem to bear out this assertion as 4 occurred in ligations of the innominate and carotid arteries, 1 in ligation of the innominate, 1 in ligations of the innominate, carotid and vertebral and 1 in

ligations of the innominate, carotid and subclavian. Of the 7 cases, 6 were associated with ligation of the carotid.

It is possible that with the subclavian tied there is a better chance of protecting the cerebral circulation than with ligation of the carotid, and certainly the incidence of thrombosis is reduced.

If the ligation of the innominate is proximal to an aneurysm, distal ligation of the carotid or subclavian and extirpation of the sac, if possible, is the best operation for cure of the aneurysm. As 56 of the 75 aneurysms involved the subclavian and 15 involved the bifurcation or

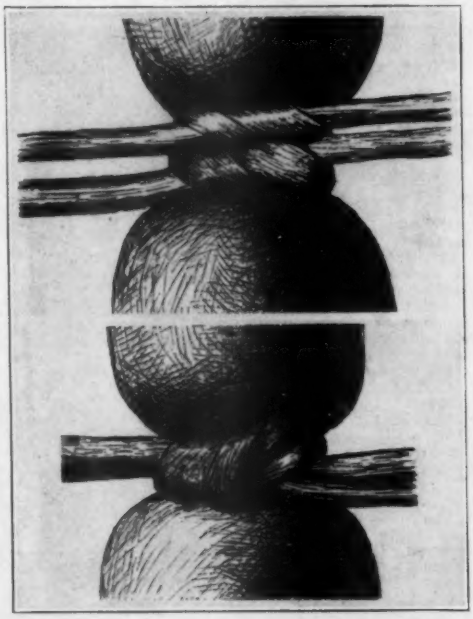

Fig. 5.—Ballance and Edmunds' stay knot.

the innominate as opposed to 8 involving the carotid, distal ligation of the subclavian would occur many more times.

There were 15 cases of proximal and distal ligation, 7 of which were done in two stages, and in 7 the sac was partially or wholly extirpated. The results showed 12 cures, 1 case in which there was no improvement and 2 deaths (table 11). This is by far the best showing in the series.

The most advisable operation from all these data would be multiple ligation, proximal and distal to the aneurysm, if possible, and with a preference for ligating the subclavian rather than the carotid artery.

The innominate was severed between ligatures in 3 cases, in 2 of which the patients recovered. This is too meager information from

which to form conclusions, but added to this there is experimental work indicating better results when the artery is cut. Horsley showed that the cut ends immediately retract. This increases the thickness of the vessel wall. The raw exposed end gets more fibroblasts from the sur-

TABLE 11.—*Proximal and Distal Ligations*

No.	Diagnosis	First Operation	Second Operation	Result	Date	Cause of Death	Aneurysm
47	Subclavian aneurysm (2)	Subclavian ligation, excision of sac	Innominate ligation	Death	1 hour	Shock	Second ruptured
51	Subclavian aneurysm	Innominate, subclavian ligation; sac partly excised	.....	Death	Hour	Shock	
54	Subclavian aneurysm	Innominate and carotid ligation	Subclavian ligation	Recovery	9 months	.....	Cured
55	Carotid aneurysm	Innominate ligation	Carotid ligation; excision of sac	Recovery	9 months	.....	Cured
56	Subclavian aneurysm	Innominate ligated and cut	Subclavian ligation; excision of sac	Recovery	7 months	.....	Cured
57	Subclavian aneurysm	Partial innominate ligation	Subclavian ligation	Recovery	15 years	.....	Cured
63	Subclavian aneurysm	Innominate, carotid, subclavian and jugular vein ligation	.....	Recovery	4 months	.....	Cured
64	Bifurcation aneurysm	Innominate, carotid, subclavian ligation; excision of sac	.....	Recovery	17 months	.....	Cured
70	Subclavian aneurysm	Subclavian	Innominate	Recovery	13 months	.....	Improved
80	Subclavian aneurysm	Innominate and subclavian artery and vein ligation; excision of sac	.....	Recovery	12th day	.....	Cured
82	Carotid aneurysm	Innominate ligation	Carotid ligation	Recovery	4 years	.....	Cured
86	Carotid aneurysm	Innominate, carotid, subclavian ligation; excision of sac	.....	Recovery	6 years	.....	Cured
88	Subclavian aneurysm	Innominate and subclavian artery and vein ligation; sac sutured	.....	Recovery	1 year	.....	Cured
89	Bifurcation aneurysm	Innominate, carotid and subclavian ligation	.....	Recovery	19 months	.....	Cured
91	Bifurcation aneurysm	Innominate and subclavian ligation; sac packed	.....	Recovery	6 months	.....	Cured

rounding tissue and cicatrizes more rapidly. If the artery is to be severed, it is advisable to apply 3 ligatures and to cut between the two distal ones. The end of the artery is then at rest because of the proximal ligature and can heal better.

Another argument in favor of severing the artery was brought forward by Leriche at the 1922 Congress of Surgeons. The vasocon-

strictor fibers running along the great vessels are only temporarily injured by ligation in continuity. They are destroyed by cutting, and the periphery therefore gets better circulation. This may be shown by tying and cutting the femoral artery. In one minute there is a flow from the distal end which in five minutes begins to pulsate. This is due to the dilatation of the anastomosing arterioles, particularly in the muscles.

Associated with the problem of severing the artery is the problem of ligation of the accompanying vein. Makins, Leriche, Brooks and Martin, Drummond and others, have shown that the peripheral circulation is improved by ligating the vein at the site of the arterial ligation, or better at a proximal point. In a series of experiments on rabbits, Brooks and Martin showed that ligation of the common or external iliac artery caused gangrene in 71.5 per cent of a series, while simultaneous ligation of the common iliac vein caused gangrene in only 33.3 per cent. The same tendency has been shown by Drummond in ligation of the mesenteric vessels. Holman quoted a series collected by Heidrich, in which gangrene developed in 15.4 per cent of 995 arterial ligations and in only 8.5 per cent of 198 arterial and venous ligations.

In ligations of the innominate there are two peripheral circulations to consider; one is that of the subclavian and the other that of the carotid. In the subclavian areas, i. e., the upper extremity, no cases of gangrene have been reported, although there are some cases of atrophy which might be considered the chronic result of anemia in which gangrene is the acute. In the 75 ligations there have been 7 cases of death from cerebral lesions. Some of these must be attributed to anemia. Ligation of the innominate vein would help the upper extremity according to the experimental work. In the case of the brain, however, the circulation differs. Here there is a right and left supply, and right and left return. Both anastomose widely, the arterial side through the circle of Willis, the venous side through the dural sinuses. Obstruction to the venous return by ligating the right innominate vein might, by increasing the resistance to outflow, increase the cerebral circulation, but without experimental data one can only theorize. At least the evidence at present is in favor of ligation of the vein.

If ligation of the innominate is contemplated, it should be done early. The operation is easier in the early stages of a vascular lesion than after marked pathologic process has developed. An operation in which the mortality in the last 25 cases was 16 per cent is certainly a justifiable procedure since the pathologic process which indicates it is of such a serious nature.

ABSTRACT OF CASES

CASE 1[2] (surgeon, V. Mott, 1818).—A white man, aged 57, was admitted to the New York Hospital, on March 1, 1818, with catarrh and swelling of the right arm and shoulder. He had fallen one week before admission, and two days later had noticed pain in the shoulder. Under medical treatment, his general condition improved and the swelling subsided in the arm and neck, leaving a definite tumor which showed faint pulsation. On May 3, something gave way in the tumor. It increased one-third in size, and pulsation became distinctly perceptible. By May 10, it measured 4 by 5¼ inches (10.2 by 13.3 cm.). The arm was useless and painful, and the patient asked for an operation.

On May 11, with the patient under 70 minims of tincture of opium, an incision 3 inches (7.6 cm.) long was made above the clavicle and a second one along the medial border of the right sternomastoid. The sternal portion of this muscle was cut, and the carotid and subclavian arteries were exposed. The latter was unhealthy. The innominate artery was dissected out bluntly. A silk ligature passed from below upward was tied around the artery ½ inch from the bifurcation. It was gradually drawn tight, causing no change in the heart or the lungs, but stopping the circulation in the temporal and radial arteries. The second knot was tied. The tumor immediately decreased one-third in size. The wound was closed about the ligature. The operation lasted one hour.

After operation, the patient was comfortable. The pulse rate was 69 and the right arm was slightly cooler than the left. The arm was wrapped in absorbent cotton. That evening the patient had a slight headache and was bled 16 ounces (473.1 cc.). On the third day, there was foul suppuration through the dressing. On the fourth day, the wound was dressed. There was healthy suppuration. The wound was united almost to the angle. There was less discharge and less odor on the eighth day; the tumor decreased two-thirds. A small slough was seen in the dressing. A hemorrhage filled the wound, but was easily stopped by pressure. On the eleventh day, the slough came away from the bottom of the wound. On the thirteenth day, the patient was weaker; the large ligature came away. On the fifteenth day, he was up and walking, and on the nineteenth day he went up two flights of stairs. On the twenty-second day, there was a hemorrhage of 24 ounces (710 cc.). The pulse ceased, but gradually recovered. On the twenty-third day, the patient was vomiting and sick. There was a foul discharge, and a hemorrhage of 4 ounces (118.4 cc.). On the twenty-fifth day, the patient died after a hemorrhage of 8 ounces (236 cc.).

Autopsy showed suppuration of the wound. The innominate artery was inflamed, and the ligature had cut through the vessel. The carotid was blocked. The subclavian was pervious and opened directly into the ulcer which was at its origin. A diseased opening in this artery communicated with the sac.

CASE 2[3] (surgeon, Graefe, 1822).—A sailor, aged 30, was admitted to the hospital in 1821, with a subclavian aneurysm of rapid growth. On March 15, 1822, an incision was made along the anterior edge of the sternomastoid, exposing the carotid artery. This was followed down to the innominate artery. The ligature was passed 1 inch from the aorta and tied.

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2. Mott, V.: Reflections on Securing in a Ligature the Arteria Innomimata, Med. & Surg. Reg. **1**:9, 1818; Further Remarks on the Case of Ligature of the Arteria Innominata, ibid. **1**:2, 1820; A Case in Which the Innominate Artery was Tied by a Surgical Operation, Am. Med. Recorder **2**:374, 1819.

3. Wagner: Ligature of the Innominate Artery, Med. & Physical J. **49**:475, 1823. Sheen: On Ligature of the Innominate Artery, Ann. Surg. **42**:1, 1905.

The ligature came away fourteen days after operation, with part of the bifurcation of the artery. There was suppuration. Hemorrhage, which occurred some time afterward, was controlled by pressure. The patient complained of pain in the tumor. Fluctuation could be felt. The sac was incised, and pus and blood drained out. The old wound healed; the new wound drained. There were hemoptysis, fever, vomiting and suppuration. The patient died on the sixty-seventh day.

Autopsy showed lung disease. The innominate artery was closed by a clot on the cardiac side. Ample anastomosis was proved by injection. The hemorrhages apparently were distal.

CASE 3[4] (surgeon, Norman, 1824).—A man with a tumor of the subclavian artery underwent an emergency operation, the innominate artery being ligated. He died on the fifth day after operation, showing acute pericarditis. The ligature was in good condition with no pus and a firm clot on the cardiac side.

CASE 4[5] (surgeon, Arendt, 1827).—A man, aged 36, was admitted to the hospital on Dec. 3, 1827, with his right arm painful, swollen and inflamed. There was a swelling the size of a goose egg, pulsating, behind the right clavicle. He had received a blow on the shoulder one year before.

On December 24, an incision 3½ inches (8.9 cm.) long was made along the inner border of the right sternomastoid. The trachea was followed down to the innominate artery. The needle was broken on the first passage of the ligature, but the second time it was successful, and the artery was tied. Pulsation in the aneurysm, subclavian and carotid, ceased at once.

After the operation, the arm was cool and dark blue. The patient was flushed and anxious, and complained of pain under the sternum. The pulse rate was 148. The patient was bled 20 ounces (591.5 cc.). On the first day after operation the arm was warmer, but swollen, numb and painful. On the second day the temperature was higher, and the pulse rate was 145, and dyspnea and hoarseness developed. The arm was less swollen. The patient was bled 10 ounces (295.7 cc.). On the fourth day thin pus came from the wound. Considerable pus was noted until the eighth day, when the patient died from exhaustion.

At autopsy considerable infection of the wound and surrounding tissue was noted. There was pneumonia in the right lung and serous pleurisy. The subclavian artery was inflamed. The innominate ligature was tight and had cut through the coats. The carotid and subclavian arteries had collapsed. There was edema of the brain and enlargement and softening of the liver.

CASE 5[6] (surgeon, Hall, 1830).—A white man, aged 52, was admitted to the hospital on Sept. 4, 1830. For seven months he had had a pulsating tumor above the right clavicle. There were loss of power and edema in the right arm, and some difficulty in respiration and swallowing. For three days he was bled 1 pint a day.

Operation was performed on September 7 with the patient in a sitting position. A midline incision was made from the thyroid body to the sternum and transversely from there to the sternomastoid. There were many diseased glands. The innominate artery was dissected out easily with the finger. It was found to be diseased

4. Polland: Statistics of Subclavian Aneurysm, Guy's Hosp. Rep. **17**:126, 1872. Gore: Ligature of the Innominate Artery for Subclavian Aneurysm, Lancet **2**:119, 1878.

5. Polland (footnote 4, first reference).

6. Hall: Case of Aneurysm of the Right Subclavian Artery in Which Ligature was Applied to the Arteria Innominata, Baltimore M. & S. J. **1**:125, 1833.

and dilated. As the finger was withdrawn, there was a slight flow of blood which became copious without pulsation. A ligature was passed around the innominate artery and tied. During application the hemorrhage ceased, but after it was tied it began again. The wound was packed with sponges. The wound was closed over this with sutures, and the hemorrhage stopped. The patient was in a poor condition.

Pulsations in the carotid and subclavian arteries were hardly present for two hours after operation. They returned to normal within the first day. Two days after operation, the patient was bled 15 ounces (444 cc.). Four days after, he was up and around and insisted on going home. There was a sudden change in the evening; the pulse rate was 134, and there were dyspnea, fever, a slight discharge from the wound and pain about the sternum. The patient died early the next morning.

At autopsy the wound was found to be badly infected. There was pericarditis. There were diseased glands along the trachea and all the great vessels were diseased. Infection and softening of the innominate and carotid arteries were noted. The ligature had been passed through the innominate, but not around it. The aneurysm contained a clot.

Case 6[7] (surgeon, W. H. Porter, 1831).—A man, aged 47, was admitted to the hospital on Dec. 6, 1831, with a large pulsating tumor filling almost the entire right side of the neck. It measured 5⅜ by 3 inches. There was severe pain in the tumor, and pain and numbness in the forearm and hand. No pulse was felt at the wrist or elbow. The hand was cold and bluish. The mass was first noticed two and one-half years ago; the pain and numbness, one year ago. The patient was treated medically for five days without improvement.

On December 10, an incision 2 inches (5 cm.) long was made from the left sternoclavicular joint to just above the head of the right clavicle, and was carried upward from its left extremity. The right sternomastoid muscle was divided. The sternohyoid and thyroid were cut. The carotid artery was anterior and was found in this region. An attempt was made to dissect the innominate with the finger. Anteriorly, this was difficult because of the sternum and the struggling and crying of the patient. On the right side there seemed to be an enormous pulsating sac. The limits on the right side could not be reached. Compression of the innominate stopped all pulsation in the vessel. After one hour and fifteen minutes the operation was abandoned, and the wound was closed with two sutures.

The patient had a chill two hours after operation. Fever developed that night. He was bled 22 ounces (650 cc.). One day after operation the pulsation seemed diminished, and the pain and numbness were gone. Two days after there were a red serous discharge from the wound and some cough. On the third day there was still some discharge, but the cough was better. On the fourth day the inflammation of the wound was gone, and there was less pulsation. On the fifth day pulsation returned in the tumor; the arm felt cold to the patient, although it was hot and dry. On the sixteenth day the wound was almost healed; the tumor was harder, firmer and probably smaller. Two months after, the tumor was one-fourth the size that it was on admission; the arm was almost normal, and the patient's health much better.

Case 7[8] (surgeon, W. Bland, 1832).—A man, aged 31, had noticed a small throbbing tumor above the right clavicle for two years. He had had pain and numbness of the right arm. On admission to the hospital, a throbbing tumor the

7. Porter, W. H.: Case of Aneurysm, Dublin J. M. & Chem. Sc. **1**:25, 1832.
8. Bland: Operation of Tying the Arteria Innominata, Lancet **1**:97, 1832.

size of a pigeon's egg was found. Despite two bleedings six months before and rest, the tumor had increased gradually in size and the patient's general health became worse. His pulse rate was from 100 to 104 until the day before admission, and then it dropped to 60 and became irregular and intermittent. A terrific pain developed in the left side.

On March 28, 1832, a vertical incision was made 2 inches long and 1 inch from the upper margin of the sternum. The sternomastoid was cut, and the sternothyroid and sternohyoid were split. The innominate was found with the finger and isolated. An aneurysm needle was passed; then a ligature of two sutures was tied firmly enough to cut the inner coat.

After operation the pulse rate varied from 130 to 140. The patient was having no pain. On the second day the right arm was as warm as the left. The tumor subsided rapidly, and the numbness was almost gone. The pulse rate varied from 126 to 138. When the wound was dressed on the third day after operation it was healthy. The tumor was reduced one-third. The patient had good use of both hands. No pulsation was felt in any branches. The patient's condition progressed until the eighth day; the pulse rate was gradually dropping, when he noticed slight numbness returning in the right hand. On the tenth day, the wound was filling in. The pus was less creamy. A slight headache occurred in the afternoon. The tumor measured from 3 to 4 inches at that time. On the fifteenth day, the pulse rate was elevated; the patient had a sore throat and experienced some difficulty in swallowing. The discharge was scanty. There was some fever. The wound was nearly closed. On the sixteenth day, the discharge became bloody. The throat was tender and painful. On the seventeenth day there was a hemorrhage of 4 or 5 ounces (118 or 148 cc.). Early in the morning of that day, the patient felt better. In the afternoon there was a few ounces of blood from the wound, and the tumor increased in size. A director was passed down to the ligature, but there was no hemorrhage. Early on the eighteenth day, there was a hemorrhage of from 10 to 12 ounces (296 or 355 cc.). The pulse became weak; the right arm became cold, and patient died at 7 a. m.

At autopsy the pleura was found to be normal. An ounce of pus was found at the base of the wound. The ligature had almost divided the artery. The innominate and carotid arteries were solid with clot; the subclavican artery was open, and the hemorrhage probably came from this point.

CASE 8[9] (surgeon, Bujalsky, 1833).—A man, aged 56, was admitted to the hospital with an aneurysm of the right subclavian artery extending from the axilla to the inferior maxilla. The skin over it was red.

On March 11, 1833, an incision was made over the tumor to the inner margin of the sternomastoid. The operation was difficult owing to old gland scars. The innominate was tied with a "tourniquet." Chills, fever and a rapid pulse developed. Death occurred on the fifth day.

Autopsy showed aneurysmal dilatation of the heart and the aorta; there was pus in the pericardium and the pleura.

CASE 9[10] (surgeon, Unknown, 1834?).—The history in this case is unknown. The innominate artery was ligated, and the patient died of hemorrhage.

CASE 10[11] (surgeon, Kuhl, 1836).—A woman, aged 43, had a malignant new growth involving both sides of the forehead. The tumor was vascular, and ligation was done as preparation for operation. An attempt was made to ligate the innomi-

9. Sheen: On Ligation of the Innominate Artery, Ann. Surg. **42**:1, 1905.
10. Dupuytren: Leçons orales de clinique chirurgical, Paris, 1834, vol. 4, p. 611.
11. Polland (footnote 4, first reference, p. 86).

nate artery, but the carotid and subclavian arteries were ligated together in one ligature ½ inch above the bifurcation. The patient was unconscious for four hours following the operation. The pulse in the right arm and right side of the head ceased. She became conscious after this, but she had difficulty in breathing and swallowing, and died on the third day.

Autopsy showed a rupture of the coats of the arteries and the canals obstructed.

Case 11[12] (surgeon, Lizar, 1837).—A white man, aged 30, was admitted to the hospital on May 28, 1837, fifteen months after a fall on the right elbow. From five to six weeks before admission, pain appeared in the right forearm and arm. No tumor had been noticed. Examination showed a pulsating tumor the size of a small egg above and medial to the clavicle. There were anesthesia and tingling in the fingers.

On May 31, an incision was made 1 inch above the sternum and 4 inches in length along the margin of the sternomastoid. The sternohyoid and sternothyroid muscles were divided. The carotid and innominate arteries were exposed. The latter were cleaned. An aneurysm needle was carried around it from the right side inward toward the trachea. The vessel was compressed, and pulsation in the tumor, the carotid and the subclavian arteries ceased. The artery was tied, and as this was done the patient complained bitterly of pain in his heart. The skin was brought together with four sutures. The operation lasted fifteen minutes.

Two hours after operation, the right side of the face was shriveled and cold. There was little difference in the two arms, except that there was no pulse in the right radial or right temporal arteries. There was pain in the course of the carotid and brachial arteries and in the back of the arm. Numbness and tingling were noted in the fingers. The left carotid was beating violently. Four hours after operation, pain was felt in the right side of the chest on deep breathing. Headache was present, but there was no pulsation. Ten hours after, the headache was worse, and there was a sensation of suffocation. On the first day, a slight pulsation was felt in the temporal artery. The patient progressed well. On the second day, he had no pain. The radial pulse was weak. The wound looked as if there would be two-thirds primary union. On the fourth day, the pulse was felt in the radial and temporal arteries, but not in the tumor. On the ninth day, there was considerable thick pus from the wound. Slight nausea occurred on the twelfth day. The patient vomited a large amount of bilious material. On the fifteenth day, the wound healed except for a small sinus which was discharging healthy pus. On the sixteenth day, the knot of the ligature was found on the dressing. On the nineteenth day, a severe, dry cough developed. A hemorrhage of 8 ounces occurred from the wound, which was stopped by pressure. The patient was bled by vein of 20 ounces. On the twentieth day, there was hemorrhage of 4 ounces, and on the twenty-first day one of from 2 to 3 ounces (59 to 89 cc.), which was stopped by lint. Evidently there was an internal hemorrhage. Cough and dyspnea developed; the patient spit blood. Death occurred at 1:30 a. m.

Autopsy showed that the innominate artery was filled with a dense clot from origin to ligation. The right common carotid was entirely clotted; the thyroid artery, internal mammary, transverse cervical, vertebral and subclavian arteries were pervious, the latter from its origin to the tumor. The aneurysm of the subclavian artery beyond this point was collapsed and contained clot. The fatal hemorrhage was apparently from the vertebral artery into the pleura, which contained 20 ounces.

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12. Lizar: Aneurysm of the Subclavian Artery Treated by Ligature of the Arteria Innominata, Lancet **2**:445 and 602, 1836. Edinensis: Mr. Lizar's Case of Ligature of the Arteria Innominata, Lancet **1**:466, 1837.

CASE 12[13] (surgeon, Hoffman, 1839).—A negro, aged 63, had a subclavian aneurysm of five months' duration. The base was 5 inches (12.7 cm.) around and extended chiefly below the clavicle.

On Oct. 26, 1839, an attempt was made to ligate the subclavian or the innominate arteries. The vessels and the aneurysm were exposed. Both vessels were too much diseased to be ligated. The patient died on Jan. 19, 1840, from exhaustion.

Autopsy showed two aneurysms of the subclavian artery, the first one measuring 1 inch, the second 6 inches (15.2 cm.) in diameter. The innominate and aorta were atheromatous, the former slightly dilated.

CASE 13[14] (surgeon, Hutin, 1841).—In a fight between two soldiers with scissors, on Oct. 28, 1841, one of them, aged 30, was wounded in the right axilla. He had a sharp hemorrhage and was brought to the hospital. The next day a wound, 6 mm. in length and 2 mm. wide, filled with clot, was present in the middle of the axilla. Four hemorrhages occurred in the next ten days, all stopping of their own accord. On November 9, owing to sudden severe pain, the wound was dressed and there was a severe hemorrhage. This was stopped by pressure on the subclavian or pressure in the wound. The third portion of the subclavian was doubly ligated, and the wound closed. The pulsation in the arm stopped, as did the hemorrhages. The patient improved for five days. He was up on the sixth day, and when attempting to defecate had a severe hemorrhage. Two more hemorrhages occurred on the following two days. On the eighteenth day, a ligature surrounded by pus was in the dressing, and there was a very severe hemorrhage. Three more severe hemorrhages occurred that day.

Operation was performed on November 27, the patient struggling throughout. The innominate artery was finally isolated and four threads in a band were placed around it. Another precautionary ligature was placed. The patient died twelve hours after operation.

Autopsy showed that the original wounded artery was the inferior thoracic. The subclavian was obliterated but had ruptured proximally at the site of the ligature. The middle and internal coats had been cut through. The ligature of the innominate artery was all right. The patient died of shock preceded by hemorrhage and operation.

CASE 14[15] (surgeon, Key, 1844).—A woman, aged 46, was admitted to Guy's Hospital on April 25, 1844, with a pulsating tumor the size of a pigeon's egg, above the right clavicle, of three months' duration. Pain was felt in the right arm. The pulses were equal, and the heart sounds were natural.

In April, 1844, an incision was made along the clavicle and sternomastoid. The sternomastoid was cut. The aneurysm was behind the subclavian artery preventing a passage of the needle. An attempt was made to ligate the innominate. This had to be given up. The operation lasted one hour.

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13. Polland: Statistics on Subclavian Aneurysm, Guy's Hosp. Rep. **16**:71, 1871. Norris: Contributions to Practical Surgery, Philadelphia, Lindsay and Blakeston, 1873, p. 284.

14. Hutin: Wound by Sharp Instrument in the Axilla; Ligature of the Subclavian, Hemorrhage; Ligature of the Innominate; Death, Ann. de la Chir. Française et Etrangere **4**:5, 1842; abstr., Lancet **2**:230, 1841.

15. Physical Soc. of Guy's Hosp., Lond. Med. Gaz. **35**:334, 1844-1845. Crisp: Structure Diseases and Injuries of the Blood Vessels, London, 1847, p. 206. Polland (footnote 13, p. 70).

Pulsation in the sac disappeared on the second day after operation. On the seventh day, a venous hemorrhage occurred. By the eighteenth day, the sac had increased, and there was much pain in the right arm. On the twenty-third day, the patient died from pressure on the trachea.

Autopsy showed that the aorta contained atheromatous deposits, and there was a small aneurysm in the thoracic portion. The carotid was healthy. The aneurysm was of the upper part of the innominate artery and origin of subclavian pressing on the right bronchus. The aneurysmal sac contained a firm clot. Death was due to pressure on the trachea.

CASE 15[16] (surgeon, Peixoto, 1851).—A physician, aged 33, nineteen years before had an erectile tumor of the right ear. The posterior auricular artery was ligated by Nelaton six years before. When the ligature fell, there was a severe hemorrhage, and several abnormal branches were ligated. The tumor recurred just before admission. On Nov. 14, 1851, the common carotid artery was ligated in the neck. The ligature was brought out through the wound. The blood supply of the tumor was shut off by this. The patient lost 5 or 6 ounces (148 or 178 cc.) of blood two or three times during a fortnight. On November 27, a chain ligature was applied about the ear. There was suppuration and the tumor became gangrenous, finally healing over with skin. On December 4, there was a slight hemorrhage from the carotid. The next day, a ligature was applied to the carotid above and below the old ligature. On December 6, two small hemorrhages occurred. On December 7, the patient tore off the dressings. There was an arterial hemorrhage of 5 ounces of blood in the evening, and the pulsations of the carotid below the ligature became sensible. On December 8, at 6 a. m. the suture points ruptured, and there was a sharp hemorrhage of half a pint.

On December 8, an incision was made along the inner border of the sternothyroid. The innominate artery was brought out by blunt dissection. A ligature was passed around it. With this in place, the old wound was opened and the clots cleaned out. The carotid ligature came away. There was no recurrence of hemorrhage. Therefore, the innominate ligature was left in place without tightening.

There was considerable cough for twenty-four hours after operation, but this cleared up. The upper wound suppurated at once. On the tenth day, both were suppurating, but the general condition was better. On the thirteenth day, the innominate ligature was withdrawn. The patient progressed to a cure in two months. Velpeau stated that there is no proof that this was the innominate artery. If it was the innominate artery, the ligature was never tightened, and although the observation was made that there was a clot in this artery, obliteration cannot be accepted as proved.

CASE 16[17] (surgeon, Pirogoff, 1852).—A man, aged 46, complained of a mass the size of a pigeon's egg in the right supraclavicular region at the site of an old abscess. The pulse at the wrists was unequal. The entire arm was painful. A diagnosis of aneurysm of the right subclavian was made.

A median line incision was made in the suprasternal fossa. The innominate was exposed and ligated.

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16. Velpeau: Report on Observation of Peixoto, Bull. Acad. de méd. **19**:452, 1853. Peixoto: Observations on the Ligature of the Innominate, Mém. de l'Acad. Imp. de méd. **19**:23, 1855; Case of Successful Ligature of the Arteria Innominata, Brit. & Foreign Med.-Chir. Rev. **18**:275, 1856; abstr., Am. J. M. Sc. **33**:255, 1857.

17. Pirogoff: Grundzuge der allgemeinen Kriegs Chirurgie, 1864, pt. 1, p. 459.

After operation the tension and pulsation decreased immediately. At the end of twenty-four hours there was severe infection of the arterial sheath. Facial paralysis developed. The patient died from mediastinitis and pericarditis in forty-eight hours.

Autopsy showed suppuration at the ligature, pleurisy, purulent mediastinitis and pneumonia. There was blood over both hemispheres of the brain. The aneurysm was of the subclavian artery.

CASE 17[18] (surgeon, Gore, 1856).—A man, aged 52, was admitted to the Bath Hospital on Sept. 22, 1856. He had noticed a swelling in the right axilla the size of a walnut three years before. This increased in size for a few weeks, and there was pain down to the elbow. It then remained the same until six months before the patient was admitted to the hospital, when it began to enlarge rapidly and the pain began to increase. On admission a pulsating tumor filled the axilla and extended up to the clavicle and scalene muscles. He was having intense pain.

On September 24, with the patient under chloroform, an incision was made a little above the inner end of the clavicle and along the border of the sternomastoid. The sternomastoid, sternohyoid and sternothyroid were cut. The innominate artery was exposed and tied with a hemp ligature passed behind from the outside. The pulse ceased in the tumor, the face and the arm. The limb was wrapped in absorbent cotton.

On the first day after operation, there was no pain. There was no pulse in the right arm or in the head, except a faint pulse in the temporal region. On the fourth day, chill and cough developed; the wound was red and discharging. The three sutures were removed. On the eleventh day, the patient had more chills. There was tension in the arm and in the tumor. On the fourteenth day, the wound was cleaner, but pulsation was noticed in the ligature. On the sixteenth day, hemorrhage occurred which lasted an hour, and was followed by death.

Autopsy showed the ligature attached to the innominate artery and partly cut through. The cardiac end was partially clogged by a firm clot. The aneurysm was small and contained a firm clot which extended to the subclavian, axillary and brachial arteries. The carotid was clotted to the bifurcation. In the anterior mediastinum there was a large cavity containing foul pus.

CASE 18[19] (surgeon, Cooper, 1859).—The patient had an aneurysm of the right carotid and subclavian arteries.

In March, 1859, an incision, 4 inches long, was made parallel to, and ½ inch above, the upper margin of the clavicle, running from inside the sternoclavicular joint to the margin of the trapezius, and joined at the middle by a vertical one. The tumor was exposed, and was found to extend beneath the clavicle. The sternal extremity of the clavicle and the top of the sternum were removed. The innominate artery was barely exposed. One third of the artery was dilated. Ligation was done ¾ inch (1.9 cm.) from the aorta.

The patient was all right for five days after operation. He sank and became restless after this. There was suppression of urine. Death occurred on the ninth day.

Autopsy showed the right side of the heart slightly dilated and pus in the right kidney. There were two aneurysms adherent to each other, one of the subclavian and one of the carotid artery.

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18. Gore (footnote 4, second reference).

19. Cooper: Aneurysm of Right Carotid and Subclavian Arteries; Ligation of Arteria Innominata, Am. J. M. Sc. **38**:395, 1859; Ligature du tronc brachio-cephalique, Gaz. hebd. de med. **8**:612, 1861.

CASE 19[20] (surgeon, Cooper, 1860).—A man, aged 31, was admitted to the hospital on Sept. 23, 1860, with aneurysm of the right subclavian artery of four months' duration. He was in good condition. There was a large pulsating mass filling the supraclavicular triangle.

On September 24, a crucial incision, 5 inches long, was made with its center on the tumor. The flaps were turned back in all directions. The aneurysm was exposed and found to be firmly attached to the sternomastoid. This muscle was cut. The scalenus anticus was also cut. There was complete immobility of the right arm from pressure on the plexus. Part of the clavicle and sternum was resected. No vessel except the innominate could be ligated proximally. The aneurysm was inseparable from the carotid artery. The innominate artery was found after forty-five minutes and ligated 1 inch from the aorta with four strands of saddler's silk. The flaps were returned to position but could not be approximated. A compress was applied directly to the exposed tumor, and 10 per cent alcohol dressings were applied with pressure.

The postoperative course was uneventful until the twenty-first day, when the patient was up and feeling fine. That evening there was a sharp arterial spurt, and the patient lost 2 ounces (59.2 cc.) of blood. The ligature came away on the eighteenth day. From the twenty-ninth to the thirty-ninth day, the patient coughed and complained of pain in the chest. The tongue was red and the urine highly colored. The wound was healed except for an opening the size of a dime at the center. In the afternoon of the thirty-ninth day, there was another slight hemorrhage, which was easily controlled by a leather cushion apparatus. Several hemorrhages occurred on the fortieth day. On the forty-first day, the patient unbuckled the strap and bled to death almost instantly.

Autopsy showed that the stump of the innominate was left in a space as large as a hen's egg where the tissue had been carried away by the hemorrhage. The lungs were congested and showed fresh pleurisy. The aneurysm was clotted and hard and about one-fourth the original size.

CASE 20[21] (surgeon, Smyth, 1864).—A mulatto, a man, aged 32, with an aneurysm of the right subclavian, was admitted to the hospital on May 9, 1864. Three months before the tumor had appeared. It was now the size of an orange with pulsation and bruit and lay in the posterior inferior triangle of the neck. The heart sounds were normal, and the pulses were equal. The patient had had considerable pain and numbness in the forearm and hand for two months.

On May 15, operation was performed, Mott's incision being used. There was no difficulty in placing a ligature ¼ inch (0.63 cm.) below the bifurcation. On tying this, all pulsation ceased. A ligature was tied about the carotid, 1 inch above its origin.

The temperature of the arm was increased immediately after operation. Two days after operation, the pulse was again felt in the wrist. Thirteen days after operation, the ligature came away. On the fourteenth day, there was a hemorrhage of 1 pint, which stopped of its own accord when the patient fainted. Slight hemorrhages

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20. Cooper: Case of Ligating the Arteria Innominata, with Remarks, Cincin. Lancet & Observer **4**:475, 1861.

21. Rogers: Case of Successful Ligation of the Innominate, Am. Med. Times **9**:95, 1864; Successful Operation in a Case of Subclavian Aneurysm, Bienniel Retrospect New Sydenham Soc. **32**:346, 1865-1866, abstr. Am. J. M. Sc. **52**:280, 1866. Smyth: A Case of Successful Ligature of the Innominate Artery, New Orleans M. J. **22**:464, 1869. Thomson: Successful Ligation of the Innominate, Carotid, Vertebral and Internal Mammary Arteries, Dublin J. M. Sc. **62**:481, 1876.

occurred the next two days, and on the sixteenth day the innominate ligature came away and the wound was filled with shot. No bleeding occurred for the next two weeks. The aneurysm became smaller and the pulsation became distinct at the wrist. On the thirty-third day, the shot was removed, and there was a severe hemorrhage. The shot was replaced. On the fifty-first day, there was a terrific hemorrhage, and the patient lost consciousness. On the fifty-fourth day, the right vertebral artery was ligated. The next day, all the shot was removed but no hemorrhage occurred. No pulsation was felt in the arm, which was cold and edematous. In a few days, this subsided. The ligature came away on the sixty-fourth day. Five years after, the patient was completely cured and had the use of his right arm. Sheen[22] stated that "Aneurysm recurred ten years later. Internal mammary artery was tied October, 1874. In March, 1875, after opening an abscess above the clavicle, the aneurysm ruptured into this cavity, and he died April 6, 1875."

Autopsy showed that the innominate artery consisted of fibrous tissue beyond the ligature which was 1 inch from the origin of the artery. The carotid artery was occluded to its bifurcation, the subclavian almost to the thyroid axis and the vertebral to the fourth cervical vertebra.

CASE 21[23] (surgeon, Lynch, 1867).—A white man, aged 23, was admitted to the hospital on Dec. 19, 1866, with a pistol wound in the right side of the neck, 2 inches behind, and a little above, the angle of the jaw. The ball was said to have come out of the mouth. The wound was plugged. The face and neck were much swollen. There had been a profuse venous hemorrhage. Hemorrhages occurred about every fourth day, until Jan. 13, 1867. On that day the common carotid was ligated. On January 27, the ligature came away. From January 30 to February 2 the patient had chills, fever and cough. On the last day there was an alarming hemorrhage from the old wound, which was packed. On February 6, hemorrhage of 2 pounds of blood occurred. The patient was very much prostrated. On February 13, another alarming hemorrhage occurred, which was thought to be from the vertebral artery.

On February 13, the innominate artery was ligated in twenty minutes.

On the sixth day after operation the patient was restless. A hemorrhage of 1½ ounces (45 cc.) occurred from the original wound. There was considerable fever. On the twelfth day, there was a profuse hemorrhage, and the patient died.

Autopsy showed the ligature in the wound surrounded by a blood clot. The original pistol wound was deep and oval, extending into the neck 3½ inches behind and above the angle of the jaw. The posterior inferior triangle of the neck contained an abscess cavity filled with a blood clot into which the internal carotid and vertebral arteries opened. A partly organized clot filled the cardiac end of the innominate. There was an artery the size of a pigeon's quill arising from the innominate near the ligature. It was thought that this kept up the circulation on the cardiac side, so that when the ligature came away the clot was blown out with a fatal hemorrhage.

CASE 22[23] (surgeon, G. H. Porter, 1867).—A man, aged 43, was admitted to the hospital on June 11, 1867, with a pulsating tumor the size of a duck's egg of fourteen months' duration. Pressure had been applied for six weeks without benefit. On June 26, with the patient under chloroform, the axillary artery was compressed with a silver wire sufficiently to stop the pulse at the wrist. On June 28, the tumor was smaller and the wire was removed. On June 30, the tumor was

22. Lynch: Ligature of the Arteria Innominata, Med. Gaz. **1**:100, 1868.

23. Porter, G. H.: Large Aneurysm of the Right Subclavian Artery Treated by Acupressure, Dublin J. M. Sc. **44**:269, 1867.

firmer. Pressure was applied with a shot bag and ice. On July 17, the wound was healed. The aneurysm continued to enlarge, but was more solid. It was decided to use pressure on the innominate with an instrument somewhat like a lithotrite.

On July 31, with the patient under chloroform, an incision was made from the anterior edge of the sternomastoid 2 inches long to the sternum and then outward 2 inches along the right clavicle. The sternomastoid was cut. The sternohyoid and sternothyroid were cut. The carotid was traced down to the innominate, and the innominate was dissected out behind the sternum. The instrument was passed around the innominate, and the artery was obliterated by making the blades approach each other. The operation took forty minutes. The wound was closed about the instrument.

After the operation the patient had pain in the dorsal region and experienced difficulty in swallowing. Five hours after operation there was a slight pulsation in the tumor. Twenty-seven hours after, the pulsation returned; when the instrument was screwed tighter, it stopped. The patient still had difficulty in swallowing. After thirty-six hours, the pulsation returned; after 60 hours, the instrument was removed and pulsation returned. The tumor was firmer; the difficulty in swallowing stopped when the instrument was removed, and there was no hemorrhage. Nine days after operation, the wound was healing and the tumor seemed as previously. In the evening there was violent arterial hemorrhage, which was controlled by pressure. On the morning of the tenth day, a slight hemorrhage occurred. A violent hemorrhage occurred at night, with immediate death.

Autopsy showed slight atheroma of the aorta and an aperture in the innominate artery just below the bifurcation, which was sloughing at the edges. There was some fibrin in the tumor. The axillary artery was narrowed at the site of that operation.

Case 23[24] (surgeon, Bickersteth, 1868).—A man, aged 42, was admitted to the hospital on April 15, 1868, with an aneurysm of the subclavian artery the size of a hen's egg, due to a strain three weeks before.

On May 5, an incision was made along the anterior border of the sternomastoid muscle and out along the clavicle. The common carotid was exposed. This was followed down to the innominate, the sheath of which was opened. A thread was passed with a needle and then a lead wire. An instrument was passed down and the lead wire drawn tight, compressing the artery. This was left on forty-eight hours, when the pulsation returned in the aneurysm. The clamp no longer worked.

On May 7, the wound was reopened, and it was found that the sawing motion had cut the lead wire. Two strong silk ligatures were tied, one above and one below the wire.

A hemorrhage occurred the fifth day after operation, and on the sixth day, three hemorrhages. Loose shot was placed in the wound, but despite this the patient died rapidly at the last hemorrhage.

Autopsy showed a healthy wound. There was a clot firmly closing the innominate artery from its origin to the ligature. The carotid and the subclavian as far as the aneurysm were empty. The aneurysm and the subclavian beyond were clotted firmly. The hemorrhage was from the distal side of the ligature.

Case 24[25] (surgeon, A. B. Mott, 1868).—The history of this case was not given. The innominate artery and carotid were ligated simultaneously. The liga-

24. Bickersteth: Case of Subclavian Aneurysm Treated by Temporary Compression of the Innominate Artery, Followed by Ligature, Lancet **2**:815, 1872.

25. Wyeth: Essays in Surgical Anatomy and Surgery, 1879, p. 168.

ture was separated on the twentieth day after operation. There was no hemorrhage from the wound. On the twenty-third day, the patient died from hemorrhage into the pleural cavity when the sac ruptured.

Case 25[26] (surgeon, Partridge, 1870).—A man, aged 32, was admitted to the hospital on April 17, 1870, with aneurysm of the right carotid artery of one and one-half years' duration. The common carotid was tied, on April 19, with the patient under chloroform anesthesia. The tumor decreased in size. On April 26, the right eye became congested and gangrenous. The ligatures separated on May 2. That evening the patient was feverish and coughed, and had a sudden arterial hemorrhage from the wound. The house surgeon stopped this by pressure of the vessel against the back of the sternoclavicular joint.

On May 2, one hour after the operation hemorrhage started. The original wound was enlarged, and the innominate artery was ligated just below the bifurcation. The patient died an hour and a half later from shock.

Autopsy showed suppuration. The cardiac end of the carotid at the ligature was open. The aneurysm was found to involve the entire extracranial internal carotid artery.

Case 26[27] (surgeon, O'Grady, 1873).—A man, aged 60, had a subclavian and axillary aneurysm of three years' duration. The inner third of the clavicle was removed. The innominate artery was exposed and tied, and the common carotid was tied near its origin. Fifteen hours after operation, the respiration was changed markedly. Serous apoplexy occurred resulting in death.

Autopsy showed good closure of the vessels and effusion into the cerebral ventricles.

Case 27[28] (surgeon, Buchanan, 1880).—A man, aged 40, was admitted to the hospital on April 19, 1880, with a pulsating tumor at the inner end of the right clavicle the size of an orange, of four months' duration. He complained of severe pain in the right arm. Medical treatment gave no relief. On May 14, galvanopuncture was done. There was oozing from the puncture hole for some time. The tumor became larger. On May 24, it measured 22 inches (55.5 cm.) in circumference. A sharp hemorrhage occurred on June 1.

On June 1, with the patient under chloroform, an incision was made along the carotid vessels and transversely across the tumor. There was a gush of arterial blood, which was controlled by hand pressure. The clots were turned out. An opening was found at the bifurcation. A finger passed behind the innominate stopped the hemorrhage. A ligature was applied. The wound was closed, but the patient died in a few minutes.

Case 28[29] (surgeon, W. Thomson, 1882).—A man, aged 49, was admitted to the hospital on Feb. 7, 1882, with an aneurysm of the right subclavian artery of ten months' duration. There had been pain in the right arm for two and a half

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26. Partridge, S. B.: Case of Aneurysm of the Right Internal Carotid: Ligature of the Common Carotid; Secondary Hemorrhage; Ligature of the Innominate; Death, Indian Ann. M. Sc. **14**:232, 1870-1871.

27. O'Grady: Ligature of the Innominate Artery at Mercer's Hospital, London, Med. Press & Circ. **15**:386, 1873. Sheen (footnote 9, p. 17); On Ligature of the Innominate Artery, Ann. Surg. **42**:17, 1905.

28. Buchanan: Aneurysm of Innominate Artery: Galvano Puncture; Rupture of Sac; Ligation of Innominate Artery, Glasgow M. J. **14**:152, 1880.

29. Thomson, W.: On a Case of Ligature of the Innominate Artery for Subclavian Aneurysm, Brit. M. J. **2**:722, 1882.

years. On admission, the tumor in the right side of the neck was pulsating violently; it measured 2½ inches in diameter. The patient was treated medically, as he refused surgical treatment. He returned on May 22. The tumor measured 3¾ inches. Pulsation ceased at times, but never for long.

On June 8, an incision was made along the sternomastoid and clavicle. The sternomastoid was turned upward. The carotid was exposed. The bifurcation was very deep. A ligature of ox aorta was passed around the innominate artery. Pressure stopped the pulsation. The ligature was tied with three knots and moderate firmness. The wound was closed with drainage at the lower angle.

The arm was protected with wadding. Partial amnesia and coldness of the left side of the face were noted immediately after operation; the pupils were equal. The symptoms were gone by evening. The patient experienced considerable pain. Two days after operation, severe pain was felt in the shoulder; there was a slight serous discharge. On the fourth day, the wound was healed except at the drainage tube. This was cleaned and replaced. On the sixth day, the tube was replaced by catgut. On the eighth day, it was draining pus. On the fourteenth day, pain developed in the right eyeball and in the head; the temperature rose in the evening. On the seventeenth day, the ligature and part of the artery came away. On the twenty-eighth day, there was pulsation at the apex of the flap; a hemorrhage of 3 ounces occurred. A severe hemorrhage occurred on the thirty-seventh day, but ceased spontaneously; more pressure was applied. On the thirty-eighth day, there was no hemorrhage, and the patient was very weak. On the fortieth day, dyspnea and much pain developed. The patient died in the morning.

Autopsy of the wound showed that the aneurysm involved the second and third portions of the subclavian artery. There was an ulceration at the junction of the three vessels with some pus, and this led to a cavity behind the sternoclavicular joint which in turn communicated with the sinus. There were clots in all the big vessels. Some pus was found. The aneurysm had a laminated clot. The innominate was blocked with a clot, which apparently became infected from the ulceration; this was probably due to pressure of the drainage tube.

Case 29[30] (surgeon, William Banks, 1883).—A man, aged 50, was admitted to the hospital on Feb. 10, 1883, with an aneurysm of the third portion of the subclavian artery.

Operation was performed on February 26, under asepsis. A silk ligature was passed about the innominate artery with some difficulty, as the bifurcation was low. This was used to apply kangaroo tendon ligatures which were tied to occlude and not crush, with three knots. Pulsation ceased in the aneurysm for two minutes. It then returned slightly, and the carotid was tied. Pulsation again ceased.

After the operation there was a slight return of the pulse during the evening. The patient was very restless the first few days. The wound healed by primary union. Pulsation returned with force on the third day, despite pressure from a shot bag. Sixty-seven days after the first operation, the subclavian artery was tied because the tumor was much worse. This was difficult owing to the size of the tumor. During the operation, the vein was opened, and air entered it. There was no bad result. The aneurysm ceased pulsating immediately. The wound was infected. The patient developed pneumonia, which cleared up, but death occurred from hemorrhage from the sinus thirty-seven days later.

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30. Barwell: Case of Simultaneous Double Distal Ligature of the Carotid and Subclavian Arteries for High Innominate Aneurysm, Brit. M. J. **1**:230, 1885. Jacobson and Rowlands: Operations of Surgery, ed. 5, p. 805.

CASE 30[31] (surgeon, Bull, 1884).—The patient had a subclavian aneurysm. The innominate, the right common carotid and the vertebral arteries were ligated simultaneously with double chromic catgut. The patient died on the thirty-third day from hemorrhage.

At autopsy the innominate was twice its normal size, thick and atheromatous. The carotid was firmly closed with a clot. The vertebral contained a loose clot, and the end of it was embedded in granulating tissue. The aneurysm was of the second and third portions of the subclavian. The aneurysm was the size of a duck's egg and contained bloody pus and clot.

CASE 31[32] (surgeon, Annandale, 1885).—A man, aged 53, was admitted to the hospital on May 14, 1885, with a swelling in the right supraclavicular region of thirteen months' duration. He had been treated medically for one month. The mass was the size of an orange and pulsated. The heart sounds were faint over the aortic area. Pain was felt in the right side of the chest and shooting down the back.

On May 27, a median incision was made and the innominate artery was exposed and compressed with an instrument behind the sternoclavicular joint. All pulsation ceased. A rubber tube was passed down so that one extremity was behind the artery and the other protuded from the wound. The operation was done under asepsis.

On the second day after operation the temperature was 102 F.; there were pain and a slight cough. On the fourth day, the wound was dressed. It had almost healed except about the tube. On the eleventh day there was a small amount of blood on the dressings. On the twelfth day, a severe hemorrhage occurred, which was stopped by pressure with the finger on a hole in the innominate artery. The compressor was applied, as ligation was impossible. The hemorrhage stopped. The patient died five days later.

At autopsy an ulceration was found on the posterior surface of the innominate artery just below the bifurcation. This was the point where the pressure of the tube was applied.

CASE 32[33] (surgeon, Helferich, 1886).—The patient, a sailor, fell and injured his right shoulder four years previous to admission to the hospital. Some months later, he noticed a tumor below the right clavicle, which pulsated. It increased in size slowly for two years, and then rapidly. On admission, Jan. 22, 1886, there was a tumor twice the size of a child's head on the anterior wall of the chest below the clavicle. Sensory disturbances were noticed in the right hand. The tumor was almost rupturing.

On January 23, an incision 12 cm. long was made along the anterior margin of the right sternomastoid. The sternal portion of the sternomastoid was cut. The innominate was exposed, and the two heavy catgut sutures were tied. The pulsation in the tumor ceased. The aneurysm was emptied by compression, but it soon refilled. The common carotid was ligated. Still the aneurysm refilled. The subclavian was ligated in the third portion. The tumor still filled moderately. The wound was closed with two drains at the upper and lower margin.

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31. Bryant: The Operative Treatment of Aneurysm of the First and Second Portions of the Subclavian, Med. Rec., N. Y. **39**:305, 1891. Burrell: Ligature of the Innominate Artery with Report of a Case, Boston M. & S. J. **133**:125, 1895.

32. Annandale: On Compression of the Innominate Artery with Notes of a Case, Lancet **1**:481, 1886.

33. Ulrich: Inaug. Dis., Greifswald, 1887, p. 14.

On the first day after operation, the patient was unconscious. There was edema of the larynx. The pulse rate and temperature were normal. Circulation in the right arm was sufficient. On the second day, the patient died.

Autopsy showed edema of the brain and anemia of the right side. The right vertebral artery was thrombosed. The probable cause of death was embolus of the brain, which was thought to result from repeated emptyings of the sac.

CASE 33[34] (surgeon, May, 1886).—A man, aged 30, was admitted to the hospital on March 3, 1886, with a large aneurysm of the right subclavian of nine months' duration. He complained of numbness and shooting pains down the arm. There was a swelling measuring 3 by 2½ inches in the right side of the neck over which the common carotid could be felt. There was pressure on the brachial plexus, with pain, numbness and atrophy, mostly in the radial distribution. No edema was present. There was some clubbing of the fingers. The right pupil was smaller than the left. Medical treatment was given for about three and a half weeks.

Operation was performed on March 27, with the patient under chloroform. An incision was made along the inner third of the clavicle, meeting another over the common carotid. The sternomastoid, sternohyoid and sternothyroid were cut. The carotid sheath was opened, and the carotid artery was traced down to the innominate, which was found to be large. Pressure on this controlled the pulse in the carotid and in the aneurysm. A needle was passed with ox aorta ligature after considerable difficulty from adhesions. This broke, and a cord of five or six medium catgut ligatures was used which was tied tight, but not tight enough to crush the artery. Three knots were used, and the ligature was cut. The wound was closed, and a tube and gauze drain inserted in one corner. The Lister spray was used. There was no pulse at the wrist or in the aneurysm.

A faint pulse was felt at the wrist four hours after operation. On the first day, pain and burning were felt in the arm. A small pulse was noted at the wrist and temple. On the second day, the wound was dressed; it was clean. The tube was removed. Pulsation had returned to the aneurysm with half the force that was noted before operation. On the ninth day, the aneurysm was smaller and harder. More pain was felt. On the fourteenth day, a small blood stain was seen on the dressing. On the fifteenth day, a sharp hemorrhage occurred; on the sixteenth day, several small hemorrhages occurred which were controlled by pressure, and on the seventeenth day, a severe hemorrhage. Death occurred on the eighteenth day.

At autopsy, the bottom of the sinus was found to be the artery. The knot could be felt in this position. There was a large aneurysm of the subclavian almost filling the thoracic aperture. All the branches of the artery opened into the sac. There was a small adherent clot and a large postmortem clot. The left carotid was small. The aorta and innominate arteries were atheromatous. There was a constriction of the vessel at the ligature. No pus was present. A small ulceration was seen under the knot. No coats were broken. The vessel was occluded except for ulceration.

CASE 34[35] (surgeon, Durante, 1887).—A white man, aged 45, was admitted to the hospital with a pulsating tumor of the right supraclavicular region, the size of an apple. For two years there had been a tingling of the right thumb, a sense of heaviness in, and vague pains over, the entire arm. The aneurysm was of the second part of the subclavian artery.

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34. May: Ligature of the Innominate Artery, Lancet **1**:656 and 1064, 1886.

35. Henderson: Ligature of the Innominate, Lancet **1**:876, 1887. Spencer: Experiments in Ligature of the Innominate, Brit. M. J. **2**:73, 1889.

Operation was performed on March 25, 1887, the incision of Mott being used. The innominate, carotid and vertebral arteries were ligated with no. 3 phenolized catgut; the innominate was ligated just below its bifurcation and again a little lower. The wound was closed with slight drainage at the inferior angle.

On the fourth day after operation, there was a slight serous drainage when the wound was dressed, and the tube was shortened. On the ninth day, the wound was united except at the sinus. The drain was removed. On the twelfth day, the temperature was 103 F. Pus exuded from the sinus, so the tube was replaced. On the thirteenth day, the temperature was 104 F. On the fourteenth day, there was right-sided hemiplegia, which disappeared in half an hour, except for paralysis of the right side of the face and of the tongue. Death occurred on the sixteenth day.

At autopsy the vessel was found closed and healed. There was an embolic softening of the left caudate nucleus of the brain.

Case 35[36] (surgeon, Lewtas, 1889).—A youth, aged 20, was admitted to the hospital on May 13, 1889. He had been wounded above the right clavicle one month before. For the past three days, he had had slight hemorrhage with acute pain in the right side of the neck, and there was a swelling as large as a fetal head. There was thought to be a foreign body present. The wound was probed without result. A piece of gun breech was removed with the finger. This caused a smart hemorrhage which could be stopped only by putting the finger into the right subclavian artery. The patient went into coma from the hemorrhage.

On May 13, an incision was made along the lower end of the right sternomastoid muscle. A catgut ligature was passed around the carotid and used for traction. By means of this, a catgut ligature was passed down around the innominate just proximal to the bifurcation and tied. The operation was stopped, as the patient's condition was desperate.

After several hours, the wound was closed and dressed, and a drain was inserted into the original wound. Both wounds healed by primary union. The patient was discharged from the hospital forty-three days later. At that time, his right hand was in a sling. There was no right radial pulse, but feeble pulsation was felt in the right brachial artery.

Case 36[37] (surgeon, Twynam, 1889).—A girl, aged 18, was thrown from her horse on July 21, 1889, fracturing her right clavicle. Five days later there was severe pain over the injury, with a swelling the size of a walnut. She was admitted to the hospital on August 19, with a diagnosis of aneurysm and fracture. She had great pain over the injury and down the inner side of the arm. The swelling measured 6 by 5 inches. Expansile pulsation was felt over the swelling.

On August 22, with the patient under chloroform, an incision was made by Spencer's method. The innominate artery was ligated ¾ inch below the bifurcation, after some difficulty in making it out. The carotid was ligated 1 inch above. The ligatures were cut short; the wound was closed without drainage. The pulse in the tumor ceased at once.

After operation, the tumor became harder. Pain became less and the arm remained warm. On the first day after operation, the patient became comatose; paralysis of the left side of the face and of the right side of the chest developed. Death occurred eighteen hours after operation.

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36. Lewtas: Traumatic Subclavian Aneurysm: Ligature of the Innominate and Carotid Arteries: Recovery, Brit. M. J. **2**: 312, 1889.

37. Twynam: Traumatic Subclavian Aneurysm: Ligature of the Innominate and Carotid Arteries; Death, Lancet **1**:1352, 1890.

Autopsy showed the sac to be coagulated, communicating with the first part of the subclavian in the anterior wall. The inner coat of the innominate was ruptured. The ligature closed the artery. Autopsy was not performed on the brain, but probably there was a cerebral thrombosis.

CASE 37[38] (surgeon, Jacobson, 1890).—A man, aged 48, had an aneurysm of one year's duration, 6 by 4 inches, in the axilla and subclavian space. He had chronic bronchitis and emphysema. In February, 1890, with the patient under chloroform, an incision was made along the right sternomastoid and the clavicle. The sternomastoid was cut. The inner third of the clavicle was resected. The innominate was found, and an ox aorta ligature was passed from without inward. The ligature was tied without injury to the coats, and pulsation ceased. The carotid was tied once, 1 inch above its origin. The wound was closed with a drainage tube.

After operation, pulsation ceased and never returned. On the third day, the aneurysm was much smaller. The patient was delirious. Death occurred on the tenth day. The wound was closed and clean.

At autopsy, pus was found about the ligatures. The vessel walls were soft. The aneurysm and vessels had clotted. There was valvular disease of the heart, and bronchopneumonia at the bases of both lungs. The brain was normal.

CASE 38[39] (surgeon, Helferich, 1890).—A man, aged 39, was admitted to the hospital on March 11, 1890, with a pulsating tumor of both sides of the neck of eleven months' duration. He had intermittent pain in the shoulder and neck and about the tumor. The tumor measured 7 by 17 cm., and extended below the manubrium. The radial pulses were equal, and the temporal pulse was weak on the right. The right pupil was larger than the left. Diagnosis of innominate aneurysm was made.

On March 21, an attempt was made to ligate the innominate artery. With the patient under general anesthesia an incision was made parallel to and above the clavicle. The sternomastoid was dissected from the tumor. The tumor was adherent. An attempt was made at subperiosteal resection of the clavicle. As the clavicle came away, there was a flow of dark fluid. This was followed by sharp arterial hemorrhage, which was controlled by the finger. There was a cavity extending deep into the thorax toward the spine. The artery could not be found. The wound was packed with iodoform gauze to stop the hemorrhage, and it was closed with silk.

After operation, pulsation in the tumor was slightly less. Suppuration began on the fourth day. No hemorrhage occurred during the first week. The packing was removed on the seventh day. There was some redness and gangrene of the skin. On the eighth day, cough and bloody sputum were noted. On the ninth day there was a hemorrhage of 500 cc., and on the fifteenth day another hemorrhage of 250 cc., which was controlled by pressure. The patient was delirious, and died on the sixteenth day.

Autopsy showed an infected wound, pneumonia and dilatation of the innominate artery. A large sac just beyond was filled with a clot. The subclavian artery was enlarged, the carotid obliterated. The sac extended to the spine and to the left carotid. There was a sinus from the sac to the operative wound.

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38. Jacobson and Rowlands (footnote 30, second reference).

39. Richter, J.: A Case of Aneurysm of the Innominate and Right Common Carotid, Dissertation, Greifswald, 1890.

CASE 39[40] (surgeon, Coppinger, 1893).—A man, aged 53, was admitted to the hospital on Dec. 5, 1892, with an aneurysm of the second and third parts of the subclavian artery as large as a hen's egg. The mass was tense, elastic and had a thrill. There was an axillary tumor the size of a walnut. The pulse at the wrist was weak. There was pain on the inner side of the forearm.

On Jan. 9, 1893, a vertical incision was made over the carotid and a transverse incision over the inner end of the clavicle. The anterior jugular vein was tied. A silk ligature was passed around the carotid, and the dissection was carried down to the innominate, which was ligated with silk from the outer side. The carotid was tied in two places and cut. The operation was aseptic and lasted thirty minutes.

On the fifth day after operation, the wound was dressed and was normal. On the twenty-seventh day, the patient was in good health. The temperature and pulse were normal for three weeks. The wound was practically closed. The right arm was normal. No pulse was felt in the radial or brachial arteries and no pain. On the forty-ninth day the condition was the same, except that the wound was healed. No hemorrhages occurred and no pulsation was felt in the aneurysm or in the brachial or radial arteries. The patient was seen on August 2, in good health, with a small hard swelling over the clavicle and no pulse at the right. The right arm was strong. Two and one-half years after operation, he was in good health.

CASE 40[41] (surgeon, Hernandez, 1894).—On March 19, 1894, in Mexico, a youth, aged 18, received a knife wound low down in the region of the right carotid artery. He tried to stop the hemorrhage with two handkerchiefs, and rushed to a nearby physician. Two physicians were present, who removed the handkerchiefs, causing a sudden increase in the hemorrhage. A surgeon was called after pressure was reapplied. A few minutes later, the handkerchiefs were entirely soaked with blood. There was no temporal pulse, and the bleeding was apparently from the carotid.

With the patient under chloroform, an obtuse incision was used as advised by Farabeuf. The innominate artery was easily recognized, and in ten minutes a silk ligature was passed about it. The former wound was then opened, and there was profuse hemorrhage. The ligature was drawn tight, but the distal end still bled. This was caught with a clamp, which was left in place, as the patient was very weak. The lower part of the wound was sutured.

Four hours after operation, the patient was given a transfusion of 400 cc. of blood. A phlebitis developed the next day, but improvement was rapid. The clamp was removed in thirty-six hours. There was slight edema of the arm and loss of radial and temporal pulsation. The arm did not work as well as normal and was a little cold. There was right strabismus and ptosis but no cerebral anemia. The circulation was reestablished, as shown by a slight radial pulsation in about thirty-six hours. One month later, the patient was well. Two weeks after, he discharged a ligature from a small abscess at the inferior end of the scar. Six years after he showed a small pulsating tumor just behind the sternum, which has been present continuously.

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40. Coppinger: Simultaneous Ligature of the Innominate and Carotid Arteries, Med. Press & Circ. **55**:153, 235 and 369, 1893; Subclavian Aneurysm, Lancet **2**: 327, 1893; **2**:236, 1895; New York M. J. **57**:388, 1893; A Case of Successful Ligature of the Innominate Artery, Tr. Roy. Acad. M., Ireland **11**:243, 1893.

41. Hernandez, Albert: A Case of Ligature of the Innominate Followed by Cure: Thirteenth Congress International de Med., Sect. de Chir., 1900, p. 309; abstr., Wien. med. Bl. **23**:559, 1900.

CASE 41[42] (surgeon, Parham, 1894).—A white man, aged 48, ten weeks before admission to the hospital, while lifting, felt a severe pain in the right side of the neck, and a small lump appeared. The right internal and external carotid arteries had been ligated. The aneurysm continued to increase. On admission, Aug. 15, 1894, the pulse was almost imperceptible in the right radial and right temporal arteries. The right vocal cord was paralyzed. The right pupil was smaller than the left. The tumor was 7½ inches (19 cm.) in circumference, and increased rapidly after admission.

On August 20, incision was made along the inner half of the right clavicle and down each side of the sternum. A 1¼ inch trephine was placed in the sternum. A small pulsating tumor was found just above the aorta. A large vessel was felt, which was probably the innominate. Ligation was impossible. The wound was packed. The patient died seventeen hours after operation, probably from shock.

At autopsy, the aorta was found to be dilated and rough. The innominate admitted the entire index finger. The aneurysm was of the bifurcation and included all three vessels.

CASE 42[43] (surgeon, Symonds, 1894).—A man, aged 53, was admitted to the hospital in October, 1894, with aneurysm of the second portion of the subclavian.

On November 5, an attempt was made to ligate the first portion of the subclavian artery through a vertical incision over the sternomastoid. As the needle passed, there was a sharp hemorrhage. This was repeated on a second attempt. A median vertical incision was made and joined to the other by a transverse incision. The sternal head of the sternomastoid was cut. The innominate and carotid arteries were tied with silk.

Two sinuses formed after operation. A piece of catgut and silk was discharged. Seven months after the aneurysm was hard. Function of the limb was returning. There was no radial pulse. The pulse was present in the carotid. In 1899, the patient was living and well.

Symonds stated in a letter on Oct. 1, 1904, that the "patient died some time ago of a general malady."

CASE 43[44] (surgeon, H. L. Burrell, 1895).—A white man, aged 54, two years before admission noticed difficulty in breathing. Six months later, he noticed a lump in the left side of the throat, which throbbed and choked him. The lump increased in size slightly. Examination on admission showed the heart enlarged with systolic and diastolic murmurs over the entire precordia. The liver was enlarged. The pulse was full in both wrists.

On July 15, 1895, an incision was made along the anterior edge of the sternomastoid muscle and outward 4 inches to the middle of the clavicle. The sternomastoid was cut at the sternal insertion. A fusiform aneurysm of the right subclavian, right carotid and innominate arteries was exposed. The upper half of the sternum and sternoclavicular joint was removed with bone forceps. The wound was kept wet because of air bubbling in the tissues, apparently from an opening in the pleura. The innominate artery was isolated and found to be 1¼ inches in diameter. A flat spatula was passed under the vessel, and a flat braided silk

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42. Parham: Preliminary Report of a Case of Immense Cervical Aneurysm Involving the Innominate Bifurcation: Unsuccessful Attempt to Pass a Proximal Ligature; Death; Autopsy, New Orleans M. J. **23**:703, 1895.

43. Symonds: Lancet, Tr. Clin. Soc. **1**:1493, 1899. Jacobson and Rowlands (footnote 38). Sheen (footnote 9).

44. Burrell, H. L.: Ligature of the Innominate Artery with Report of a Case, Tr. Am. Surg. Assn. Phila. **13**:291, 1895; footnote 31, second reference.

ligature was passed with an aneurysm needle and tied with the square knot. This was gradually tightened until the coats gave way. A second ligature of silk was placed in the same way ½ inch distal to the first, and was not tied quite as tight as before. The intention was to cut the artery, but this procedure seemed too dangerous. The wound was closed tight. Operation lasted one hour and fifteen minutes.

After operation, pulsation had disappeared from the neck and from the right carotid and the radial arteries. Cotton was packed around the arm. The right pupil was larger than the left; the right ear drum was anemic. There was no pain. On the second day, there was capillary circulation in the nails. On the fifth day, the fingers were pink and could move. On the sixth day, the wound was dressed. There was violent pulsation over the sternum. There was a small radial pulse. Some sutures were removed. On the seventh day, the numbness and prickling disappeared. On the tenth day, the wound was healed and all stitches removed. On the fifty-third day, there was slight swelling of the right arm, which lasted from three to four days. During this time, the patient was up and around. He left the hospital on the seventy-third day. He returned on the hundredth day with edema of the arm, and died suddenly on the hundred and fourth day.

Autopsy revealed hypertrophy and dilatation of the heart and of the aorta, with atheromatous patches. The right subclavian artery was dilated. The innominate artery was completely closed at the origin of the subclavian and carotid arteries. It was dilated proximally to this point. A ligature was found embedded in the walls of the artery. The lower ligature had severed the artery, but healed. Syphilis was made out on microscopic examination. Collateral circulation was found to be through the right carotid and the vertebral of the subclavian.

Case 44[45] (surgeon, R. H. Harte, 1896).—A colored man, aged 26, was admitted to the hospital on May 31, 1896, with a pistol wound of the neck. The bullet entered the neck on the left side. The left arm was paralyzed. The forearm and hand were normal. There was dysphagia. A roentgenogram taken on June 1 showed the bullet on the right side of the neck anterior to the seventh cervical vertebra.

Operation was performed on June 1, with the patient under ether. An incision was made in the right side of the neck behind the posterior margin of the sternomastoid. The bullet was found in a pocket of pus close to the esophagus, behind the common carotid artery just above its origin. On June 4 a fistula developed, which soon healed. On June 12 there was a sudden hemorrhage, which was controlled by packing. On June 14 there was another sudden hemorrhage, which was controlled by placing a finger in the depth of the wound. On July 16 an incision was made in the line of the carotid vessels, exposing the common carotid. A ligature was placed around them, but this did not stop the bleeding. The sternal end of the clavicle was dislocated; an abscess cavity was found at the bottom of the wound. Another ligature passed just above the origin of the carotid entirely controlled all bleeding. On July 26 there was a second hemorrhage. The patient was in a poor condition, but bleeding was controlled by a finger.

On July 26, the old wound was opened. The proximal end of the carotid was found to be open; the clavicle was turned outward. The innominate artery was found and ligated with silk a short distance proximal to its bifurcation. The right subclavian and the carotid arteries were also tied. The right internal jugular was ulcerated, so that it ruptured and was tied with a double ligature. The edges

45. Harte, R. H.: Ligation of the Innominate Artery for Hemorrhage with Report of a Case, Ann. Surg. **26**:489, 1897.

were approximated with silkworm gut. The patient was given an infusion, but died in a few hours.

Autopsy showed that the esophagus was ulcerated, and had a fourth of an inch opening. There was an abscess of the brain in the right temporosphenoidal lobe.

CASE 45 [46] (surgeon, G. W. Gay, 1896).—A white woman, aged 39, had noticed dyspnea and dysphagia and painful pulsation at the root of the neck for two years. There was a dull, aching pain in the back of the right axilla. During the six months before admission to the hospital all the symptoms had grown worse. On admission, Oct. 19, 1896, there was a tumor 1½ inches in diameter in the right side of the neck.

Operation was performed on October 27, with the patient under ether, and sitting in a chair. An incision was made from the left sternomastoid down to the sternum and out along the right clavicle. The sternomastoid muscle was divided. The sternoclavicular joint and the upper portion of the sternum were removed. The innominate was exposed, and the sheath was opened. The artery was found to be 2 inches long and 1 inch in diameter. Three ligatures of braided silk were used, the first one ¾ inch from aorta, the second ½ inch distal to this and the third one in the same place. All the ligatures were passed from within out, tied with square knots and cut through. The wound was closed in layers with silk, and a small silk drain was placed at the angle. The arm was wrapped in absorbent cotton. The operation lasted one and one-half hours.

After operation, pulsation in the tumor and radial arteries ceased at once. Seven hours later, there was slight pulsation in the right radial artery. On the fourth day, the wound was dressed and was found to be normal. On the sixth day, the temperature was 100.4 F. There was infection of the wound; the flap was red and swollen, but the patient's general condition was much better than before operation. On the tenth day, the wound was healed except for a small sinus at the angle 1½ inches long. On the twenty-third day, the sinus closed. On the thirty-second day, while the sinus was being washed out, a slow welling up of blood occurred which was easily controlled by pressure. Ether was given. The incision was opened. A small cavity was found with a sinus extending toward the deep ligatures. The right carotid was exposed and tied with silk 1 inch from its origin, and the wound was closed. The sinus was packed with iodoform gauze. On the thirty-fourth day, the temperature was 104.5 F. A brisk hemorrhage occurred. On the thirty-fifth day, there was a hemorrhage. On the thirty-sixth day, the sutures were removed. The temperature was normal. On the thirty-eighth day, the patient had some difficulty in moving the right arm. It felt numb and cold. On the thirty-ninth day, a profuse hemorrhage occurred. On the forty-first day, the temperature was 105 F. at night. There was a severe hemorrhage, and the patient died.

Autopsy showed a cavity about the innominate artery the size of a walnut communicating with the sinus and filled with clot and serum. Two ligatures were found together about the innominate in this cavity. The single ligature proximal to this and the artery were lost. The carotid was closed by a ligature. The subclavian artery and branches were much dilated. A diagnosis was made of rupture of the innominate artery proximal to the ligatures. Myocarditis, arteriosclerosis and multiple abscess of the kidney were found. *Staphylococcus aureus* was cultivated from the heart, liver, spleen and kidney. Microscopic examination

46. Gay, G. W.: A Case of Ligature of the Innominate Artery for Aneurysm, Boston M. & S. J. **137**:73, 1897.

of the arterial wall showed it to be necrotic, with staphylococci present. It was found on investigation that a new sterilizer had been used for ligatures, which was later found to be faulty.

CASE 46[47] (surgeon, Schumpert, 1898).—A negress, aged 42, was admitted to the hospital with a pulsating tumor the size of a large marble behind the inner third of the right clavicle. She suffered from dyspnea and a dull aching pain in the tumor. A diagnosis was made of aneurysm of the common carotid near its origin.

An incision 7¼ inches long was made at the anterior border of the sternomastoid down across the sternum. The sternal portion of the sternomastoid was cut. The anterior jugular was ligated. The carotid artery was exposed, and traced. The aneurysm was found to be of the bifurcation. The innominate artery was traced down to the aorta and ligated ¼ inch from the aorta with no. 8 braided silk passed from within out and tight enough for occlusion without severing.

After operation, the wound healed by primary union. There was a difference in temperature in the two arms during the first two days. The pulse rate was 40 for the first forty-eight hours, then 68. No pulse was felt in the arm or temple. On the fifth day, the patient was in coma and she died on the following day.

Autopsy showed some softening and slight atrophy of the right side of the brain. The ligature was encysted without inflammation.

CASE 47[48] (surgeon, B. G. A. Moynihan, 1898).—A white man, aged 31, noticed a pulsating tumor on the right side of the root of the neck fifteen months before admission to the hospital. This gradually increased in size. There was a history of syphilis. The left radial and brachial pulse was absent. On admission, there was a large mass the size of a hen's egg, with expansile pulsation. The heart was normal. The right pulse suddenly stopped twenty-three days after admission. It returned later, but the tingling and aching in the arm continued. On Dec. 8, 1897, through an incision with resection of the clavicle, the aneurysm was resected between ligatures of the second portion of the subclavian and axillary arteries. On December 13, there were infection and erysipelas and a temperature of 104 F. On December 20, there was considerable drainage of pus. On December 25, the condition was the same. On Jan. 9, 1898, the gland in the axilla was incised, and antistreptococcus serum was given. There was a sudden hemorrhage from the flap which was controlled by pressure. On February 8, there was another hemorrhage. The wound was opened, and the subclavian was found to be bleeding very deep.

On this same day curved incision was made about the sternoclavicular joint, concave, upward and outward. The upper fourth of the sternum and the inner third of the clavicle were resected after holes had been bored. The innominate artery was reached immediately and the ligatures placed. The innominate and carotid were ligated and the hemorrhage stopped, but the patient died from shock one hour after operation.

Autopsy revealed a second aneurysm of the subclavian distal to the vertebral, which had ruptured.

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47. Schumpert: Ligature of the Left Subclavian: Ligature of the Innominate Artery for Innominate Aneurysm, Also First Portion of Left Subclavian, Med. Rec. **54**:337, 1898.

48. Moynihan, B. G. A.: A Case of Subclavian Aneurysm Treated by Excision of the Sac, Ann. Surg. **28**:1, 1898.

CASE 48[49] (surgeon, A. L. Bennett, 1898).—A native in French Congo, aged 55, while on a walking trip in May, 1899, developed marked dyspnea and swelling in the right side of the neck, which had been progressing for many years. The right pupil was greater than the left. The trachea moved with the swelling, but there was no large tug.

Operation was performed on May 12, 1898. The anesthesia was administered, with the aid of native assistants, and the patient prepared for operation with soap, water and alcohol. An incision 10 cm. long was made along the sternomastoid and 11 cm. parallel to the clavicle. The sternomastoid muscle was cut. A large aneurysm of the carotid and first part of the subclavian was exposed. Part of the sternum and clavicle was cut away with much difficulty. Two flat tape ligatures, 3 cm. wide, were passed around the innominate artery with an aneurysm needle. One was tied 1 inch from the aorta, the other some distance distally, and the innominate artery was cut between the ligatures, leaving a 5 mm. stump on the proximal side. The operation was dry. All pulsation ceased at once in the neck, and there was no pulse at the wrist.

After the operation the patient did well until the third night, when he died suddenly from secondary hemorrhage. No autopsy was obtained.

CASE 49[50] (surgeon, B. F. Curtis, 1899).—A white man, aged 55, was admitted to the hospital with intense pain in the right arm of some months' duration. The heart was hypertrophied. There was generalized arteriosclerosis, especially of the right subclavian and axillary. Under the right clavicle there was a swelling 2 inches in diameter with expansile pulsation.

Operation was performed on Dec. 2, 1899. The sternum was split and divided transversely just above the second rib. The carotid and the subclavian were found, and then these were traced down to the innominate, which was isolated. A double heavy chromic catgut ligature was applied anc. tied simultaneously ¾ inch proximal to the bifurcation, but not with a stay knot. The artery walls were folded in easily. The ligature was tight enough to stop the pulsation, but not tight enough to injure the coats. Another single ligature was placed obliquely, distal to the double ligature. The bone was united with heavy wire. The wound was closed without drainage, except the lower angle between the skin and sternum.

For two days after operation there was considerable pain. The temperature varied from 102 to 104 F. The pulse rate was slow. No cerebral disturbance was noted. Four days after operation, there was a slight pulsation in the aneurysm and in the right radial artery. Four weeks after, when the patient got up, the pulsation increased. There was also pulsation in the carotid. Six weeks after operation, a small abscess at the upper angle of the scar was opened. On March 13, 1900, the common carotid and first portion of the subclavian were ligated distally to the superior thyroid branch. The pulse stopped in the aneurysm but not in the subclavian artery. The clavicle was wired, and the wound was closed. The temperature rose to 102 F. The inferior upper angle suppurated. There was some osteomyelitis. The wire was removed and fibrous union occurred. On October 29, the patient was in good condition with a strong union of his clavicle and no aneurysm.

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49. Bennett, A. L.: Ligature of the Innominate for Aneurysm of the Right Common Carotid and Subclavian, Colorado M. J. **6**:467, 1900.

50. Curtis, B. F.: Ligature of Innominate Artery, Ann. Surg. **31**:626, 1900; Milton's Method of Exposing the Anterior Mediastinum Modified for Ligature of Innominate Artery, ibid. **34**:472, 1901.

CASE 50[51] (surgeon, DeLaup, 1900).—A negro, aged 58, was admitted to the hospital on June 2, 1900, with a pulsating tumor the size of an orange in the right side of the chest of six months' duration. Constant pain was felt in the right shoulder for several weeks. There was general arteriosclerosis. The heart was enlarged, a double murmur being heard. After two weeks of medical treatment, he showed no improvement.

On June 16, with the patient under chloroform, an incision 3 inches long was made from the trapezius to the sternomastoid. The aneurysm was found to be of the second and third portions of the subclavian. The incision was prolonged to the manubrium, and the sternomastoid, sternohyoid and sternothyroid were cut. The inner part of the clavicle and part of the manubrium were resected. A fusiform aneurysm of the bifurcation of the three vessels was found. The innominate artery was twice the normal size at its origin. A kangaroo ligature was tied 1 inch from the aorta with three square knots without rupturing the coats. A kangaroo tendon ligature was tied to cause complete obstruction half way to the aorta. A braided silk was tied distally, probably rupturing the coats, but completely obliterating the radial pulse. All ligatures passed from within out. The operation lasted two hours. There was some shock, and therefore the wound was closed without ligation of the carotid.

After operation pulsation was absent in the aneurysm and subclavian artery. The arm was wrapped. A slight pulse was felt in the right radial artery at the end of four hours. On the first day, the patient had headache and was restless and mentally dull. On the third day, the tumor was denser and smaller; the dressing was stained. On the sixth day, pus was present at two sutures. On the eight day, there was a sinus 1½ inches deep. On the tenth day, delirium became worse. On the eighteenth day, slight hemorrhage occurred. For fear of further hemorrhage the carotid and vertebral arteries were tied with silk, with the patient under chloroform anesthesia. He died as the wound was closed.

Autopsy showed a hypertrophied heart and valvular disease. The innominate was surrounded by a thick ring of tissue. The silk ligature was in the lumen. The kangaroo ligature was absorbed. The sinus did not communicate with the lumen. Circulation was apparently reestablished. The carotid and subclavian arteries and their branches were dilated. The aneurysm of the third subclavian and axillary was clotted.

CASE 51[52] (surgeon, von Ruediger, 1901).—A woman, aged 37, had noticed a swelling in the right shoulder and neck for five years. The right arm became weaker, and for one year there was severe headache, hoarseness and dyspnea. There was a pulsating tumor the size of a hen's egg under the right sternomastoid. The growth extended under the clavicle and sternum. The temporal pulse was weak on the right, and the right radial pulse was lacking. The right arm was weaker than the left. There was vocal paralysis on the right side. A diagnosis of innominate aneurysm was made.

On March 19, 1901, a curved incision was made, concave upward and outward. Part of the sternum and clavicle was resected. An enormous aneurysm extending into the thoracic cavity was exposed. The three great vessels lay on the anterior surface. The subclavian artery was finally discovered to communicate with the aneurysm. The subclavian was ligated distal to the opening.

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51. DeLaup: A Case of Ligature of the Innominate Artery for Aneurysm, Phila. M. J. **7**:171, 1901.

52. Von Ruediger: A New Method of Ligation of the Innominate Artery, Wien. klin. Wchnschr. **19**:1514, 1906.

The innominate artery was ligated because of the difficulty of ligating the first portion of the subclavian. Pulsation stopped at once. The aneurysm was opened and bled severely. The sac was partially extirpated. The wound was packed and closed around the drains. The operation lasted two hours and fifteen minutes. The patient died of shock despite hypodermoclyses.

At autopsy the pathologic process described at operation was found. The aneurysm extended down into the thorax on to the right lung and was adherent to the pleura. There was edema of the lungs.

Case 52[53] (surgeon, C. A. Ballance, 1902).—A man, aged 35, was admitted to the hospital on March 27, 1902. In the right root of the neck, there was a slight swelling 9 cm. long with expansile pulsation. The swelling extended under the manubrium. The right radial and carotid pulses were smaller than the left. The right pupil was smaller than the left and the right vocal cord was partially paralyzed. There was pressure on the right lung. The heart and aorta were normal. There was pain in the tumor, and the patient had a hacking cough. Medical treatment was given without effect.

On April 15, with the patient under chloroform, a median incision was made from the thyroid cartilage to the manubrium. The sternohyoid and sternothyroid muscles were separated. A finger was passed down beside the trachea to the arch of the aorta. The innominate was normal for the first half inch. The manubrium was incised vertically to the upper border of the second costal cartilage, cut across at this point and pulled apart. One-half inch of bone was removed from each side. The vessel was cleared, and a needle with four strands of gold-beater's skin (ox peritoneum) no. 4 was passed. This was tied with a stay knot, occluding without injuring the coats. The pulsation in the aneurysm ceased at once; the common carotid, which was distended but not pulsating, was tied with two strands of the same. This was needless, due to a clot. The wound was closed.

After operation there was no pulse in the right radial artery, and the right side of the face was colder than the left. Breathing was labored on the morning after operation. There was a left hemiplegia that night, and the patient died.

At autopsy the common carotid, internal carotid and middle cerebral arteries were thrombosed. No other disease was found. There was an aneurysm of the carotid, subclavian and innominate arteries.

Case 53[54] (surgeon, Persons, 1904).—The patient was in the Naval Hospital at Norfolk, Va., for two weeks with repeated hemorrhages from a laceration of the right axillary artery. The bleeding point could not be located. Operation was performed, but after an ineffectual attempt to find the subclavian artery, owing to a clot, the innominate was ligated at the bifurcation. The patient died.

Case 54[55] (surgeon, Sheen, 1904).—A white man, aged 46, had an aneurysm of the second and third parts of the subclavian artery of six months' duration. There was a pulsating swelling above the middle of the clavicle, 6 by 5 cm., extending from the sternomastoid to the trapezius muscle. The right radial, brachial and axillary pulse were just perceptible. The temporal and the carotid pulse were equal on the two sides. The fingers were bluish white.

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53. Ballance, C. A.: Aneurysm Involving Innominate, Subclavian and Carotid Arteries, Treated by Proximal Ligation, Lancet **2**:1180, 1902; Ligation of the Innominate Artery Innominate Aneurysm, Brit. J. Surg. **9**:438, 1921.

54. Persons: Ligation of the Right Innominate Artery, Rep. Surg.-Gen. Navy, 1904, p. 272.

55. Sheen: A Case of Ligature of the Innominate Artery, Brit. M. J. **2**:870, 1905; footnote 9.

On March 31, 1904, with great attention to asepsis and with the patient under chloroform, a median incision, 5 inches long, was made from the cricoid cartilage to the sternal notch. The carotid vessels were exposed and traced down. In dissecting the first part of the subclavian, the pleura was opened. This was packed with gauze. The innominate was exposed; two ligatures of stout floss silk were passed from without inward and tied with a Ballance and Edmunds' stay knot to occlude completely without injuring the coats. When the ligature was tightened, the temporal pulse disappeared. The carotid was tied with one suture in a surgical knot. The wound was closed tight.

Mental disturbance was noted for two days after operation. One day after, there was a slight return of pulsation. This increased for four days and was gone on the eighth. It increased later, but never was as strong as before operation. The pain continued. There was primary union of the wound. There was slight recurrent paralysis on the right side. The right radial pulse returned on May 17. On May 19, an attempt was made to ligate ½ inch proximal to the sac; this was not successful, owing to bleeding. On June 2, the aneurysm and first part of the subclavian were exposed. A stout twist was passed around the latter and tied with a surgical knot. The pulsation ceased. The second suture was passed distal to the first. There was primary union. Circulation was not as good after this operation. Three weeks after this, there was no return of pulsation. Pain and tingling were much less. The radial pulse returned two months after operation. On December 16, the sac was flat, and had no pulsation. There was a slight pulse in the right radial and temporal arteries. None was felt in the right carotid and brachial arteries. The enlargement of the veins had disappeared. The pain was slight. The patient's condition was good.

Case 55[56] (surgeon, Saigo, 1094).—A soldier, aged 22, was shot in the right side of the neck on Oct. 14, 1904. The shot went through the neck from the anterior border of the right sternomastoid to 2 cm. from the spine of the first dorsal vertebra. An aneurysm developed, with pain, difficulty in swallowing and ptosis on the right side. Pain was felt also in the arm down to the little finger. The tumor increased in size, the skin became tense and bluish and right-sided headache developed.

On November 23, with the patient under chloroform, a T-shaped incision was made over the clavicle and manubrium. The sternal end of the sternomastoid was cut. Part of the clavicle and part of the manubrium were resected. The innominate artery was isolated and ligated. The aneurysm was of the right carotid The wound was closed with drainage.

On the first day after operation, there was pain in the wound; the pain in the arm and head was gone. No radial pulse was felt. There were slight emphysema and difficulty in swallowing. On the second day, the drain was removed. The tumor was smaller, and there was a large amount of grayish discharge. On the sixth day, the wound was reopened. There was a moderate amount of pus. The emphysema disappeared. On the tenth day, the tumor began to pulsate again. On the fifteenth day, the skin broke down and discharged tarry fluid. Healing was uneventful from that time. In August, 1905, ligation was done above and below the aneurysm, and the sac was resected. The patient made a good recovery.

Case 56[56] (surgeon, Saigo, 1905).—A soldier, aged 24, was shot just above the right clavicle on March 5, 1905. He developed a varicose aneurysm of the right

56. Saigo: Traumatic Aneurysm in the Russo-Japanese War, Deutsche Ztschr. f. Chir. **85**:577, 1906.

subclavian artery and vein. The wound healed in fifteen days. Severe pain was present over the tumor.

On April 6, 1905, with the patient under chloroform, an incision was made along the right clavicle with resection of its inner third. The innominate artery was doubly ligated and cut.

After operation the patient complained of cold in the right temple and cheek. The tumor recurred after thirteen days. The right pulse was weaker than the left. The right arm was emaciated. On August 4, an operation was again performed in the original scar. The new bone was resected. The subclavian artery was exposed. The aneurysm was excised after ligation of the subclavian artery and vein, proximally and distally. The pain was better after this operation. The patient was discharged on November 2.

CASE 57[57] (surgeon, W. S. Halsted, 1905).—A white woman, aged 50, was admitted to the hospital on Oct. 17, 1905, with aneurysm of the right subclavian artery of six years' duration. The aneurysm was wired in December, 1904. The heart was normal. There was a tingling in the fingers, but no paralysis of the nerves. The radial pulse was a little delayed. The tumor measured 7 by 8 cm.

On Nov. 17, 1905, two thirds of the clavicle and part of the first rib were resected. The innominate artery was partially ligated with a no. 33 aluminum band 1.5 cm. wide, wrapped twice around the artery and held in place by a heavy black silk ligature.

After operation the pulsation was reduced somewhat by the application of the band; the size was unchanged. On January 12, the blood pressure of the right arm was 100 and of the left arm 102. The subclavian artery was ligated. Pulsation in the aneurysm persisted after ligation on both sides of the aneurysm. There was no pulse in the tumor at the first dressing after the second operation. The patient was well on February 10. She was readmitted to the hospital on March 31, 1921. The aneurysm had disappeared. Function of the arm was not impaired. There was dilatation of the common carotid distal to the band.

CASE 58[58] (surgeon, Cuneo, 1905).—A woman, aged 49, was admitted to the hospital on Dec. 12, 1905, with an aneurysm of the aortic arch. She had had increasing dyspnea for six years, and the medical treatment had not improved her. She was hoarse, had severe dyspnea, was weak and emaciated and had severe pain.

On December 13, with the patient under chloroform, a right angle incision was made, and the sternomastoid was cut. The inferior thyroid veins were cut and tied. The innominate artery was tied at the middle with no. 2 silk, and the respirations ceased momentarily. The innominate artery was dilated proximally, being involved in the aortic aneurysm. The wound was closed without drainage.

After operation the radial pulse stopped but returned the next day, with no change in the pupil. The temporal pulse was present throughout. The first day after operation, the dyspnea was better and the tumor was small. The patient was discharged at the end of one week. She was in the hospital again from Jan. 12, to March, 1906, with bronchopneumonia. In December, 1910, she was living, and was much better than before the operation. The dyspnea was not so severe. There was no cough. The tumor was present, but was much harder.

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57. Reid: Aneurysms in the Johns Hopkins Hospital, Arch. Surg. **12**:1 (Jan.) 1926.

58. Guinard: Ligation of the Innominate Artery for Aortic Aneurysm, Bull. et mém. Soc. de chir. **37**:800, 1911.

CASE 59[59] (surgeon, Curtis, 1907).—A white man, aged 59, was admitted to the hospital on Jan. 4, 1907, with aneurysm of the right subclavian artery.

Operation was performed on January 11. The manubrium was split to a point below the second rib and forcibly separated 1½ inches. The innominate artery was exposed and ligated with no. 4 chromic catgut. Two ligatures were laid side by side and tied separately 1 inch above the origin of the artery. Another double ligature of the same was tied ½ inch distal to the first, and the two threads were tied together. The bone was sutured with chromic catgut. There was no drainage.

All pulsation ceased in the arm, carotid and aneurysm immediately after operation. The pulse in the external carotid returned in two hours. The patient developed bronchopneumonia, and died four days after operation.

Autopsy showed an uninfected wound. Both ligatures were present, but the proximal was driven forward to the distal by pulsation. The internal coats were not ruptured. The vessel was folded together and closed. A clot filled the distal innominate, the subclavian and the aneurysm. The origin of the common carotid was also filled, but the artery was patent at its bifurcation. There was no clot in the innominate, proximal to the ligatures. The lungs showed purulent bronchitis and bronchopneumonia.

CASE 60[57] (surgeon, W. S. Halsted, 1907).—A colored man, aged 51, married, had an aneurysm of the innominate artery of one month's duration. The tumor increased from a small lump to the size of a baseball in one month. There was numbness in the right hand. The right pupil was smaller than the left. The symptoms began with a cough; then there was pain in the neck, ear and chest. The heart was possibly enlarged. The tumor measured vertically 8 by 11 cm. The right radial pulse was more compressible than the left.

On February 2, the innominate artery was ligated for an aneurysm involving the subclavian artery. Three heavy, braided white silk ligatures were tied close together, the most distal one completely occluding the artery. There was a small iodoform pack placed to a point of rupture in the pleura.

The pulse was felt at the wrist and in the temporal artery at 5 p. m. on the day of operation. There were no sensory disturbances. The next day the blood pressure in the right arm was 65, and in the left 124. Some edema of the arm was noted, but this subsided markedly. The grip was slightly weaker. The aneurysm continued to pulsate with two thirds of the former force. It became smaller, measuring 7 by 7 cm. On February 20, partial ligation of the right common carotid artery was performed and an aluminum band 8 mm. wide was placed above an aneurysm involving the subclavian, common carotid and innominate arteries. The band almost occluded the artery just below the bifurcation. That afternoon, at 3 p. m., the blood pressure in the right arm was 100, and in the left 145; at 8 p. m. it was 85 in the right arm and 145 in the left. After the second operation, the aneurysm was unimproved. It increased in size. The grip in the hand became weaker. The patient was discharged on June 11. He died on Jan. 1, 1908, of pneumonia. Autopsy was refused. The wife said that the aneurysm stopped pulsating and became hard before death.

CASE 61[60] (surgeon, W. B. Burns, 1907).—A colored man, aged 27, was admitted to the hospital on Aug. 6, 1907, with swelling above the right clavicle

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59. Curtis: Ligature of the Innominate Artery, Ann. Surg. **45**:966, 1907.

60. Burns, W. B.: Successful Ligation of the Innominate Artery, J. A. M. A. **51**:1671 (Nov. 14) 1908.

of one year's duration. Pain had been felt in the shoulder and down the arm for five months. The arm and hand were edematous and numb.

Operation was performed on August 9, with the patient under ether, Mott's incision being used. One ligature, with the largest size of braided silk, was tied around the innominate artery 1 inch from the bifurcation in a granny knot. The ligature was tight enough to approximate the vessel walls, but not to crush them. The operation lasted one hour and twenty minutes. Pulsation ceased at once.

On the second day after the operation, the edema, pain and numbness were gone. On the fourth day, there was suppuration of the wound. On the fifth day, counter openings were made, and wicks were inserted. The temperature fell and remained normal until the fourteenth day. On the fourteenth day, there was a hemorrhage which was controlled by packing and tight dressing. On the sixteenth day, a small hemorrhage occurred, the temperature rising to around 101 F. On the eighteenth day, there was another small hemorrhage. On the twenty-first day, the ligature was removed from the wound.

CASE 62[61] (surgeon, Myles, 1908).—A man, aged 29, had a subclavian aneurysm. A median incision was made low in the neck, and the innominate artery was ligated. The right common carotid was doubly ligated and divided. The wound healed by primary union. Pulsation continued in the aneurysm, and ten days after operation there was a large subcutaneous hemorrhage. The wound was opened, and the stumps of the vessels were clamped and tied. Suppuration followed this operation, and the patient died at the end of one month.

Autopsy showed that the ligatures had slipped from the carotid artery.

CASE 63[62] (surgeon, Herzen, 1908).—A policeman, aged 30, was shot in the right side of the neck, in the right arm and the right leg seven months before admission to the hospital. On the way to the hospital, he broke the right clavicle. The wound bled severely, and he was unconscious for three days. Three months later, a slowly increasing aneurysm appeared, with swelling of the right cheek and arm. On his second admission, he showed scars of the right leg and arm and at the right of the trachea, and the bullet was still in the neck. There was a pulsating tumor the size of a walnut behind the sternoclavicular joint on the right. No temporal pulse was felt; the radial was present on the right. There were contracture and paralysis of the right arm, particularly at the shoulder. The arm was painful and sensitive. Almost the entire brachial plexus was involved.

On October 4, with the patient under ether and choloform, a median incision of the neck was bisected by a horizontal one along the clavicle. The flaps were retracted. All veins were bleeding, with pulsation. The inner third of the clavicle was removed, and part of the sternum. A large adherent aneurysm was present. The innominate artery was exposed and ligated with silk thread. The pleura was opened by accident and packed. The right radial pulse ceased after ligation. The carotid was cut between the ligatures. The subclavian was ligated at its origin. The aneurysm was dissected out. The jugular and subclavian veins were ligated. The wound was closed with two gauze drains.

On the first day after operation, cough and pleuritic pain developed. The drains were removed with much bloody discharge. The right pulse was weak. On the fourth day, there was some cyanosis of the hand. On the sixth day, the

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61. Myles: A Case of Ligature of the Innominate Artery, Dublin J. M. Sc. **124**:474, 1907; A Case of Ligature of the Innominate Artery, Tr. Roy. Acad. Med., Ireland **26**:278, 1907-1908.

62. Herzen: Ueber ein Fall von Unterbindung der Art Anonyma, Deutsche Ztschr. f. Chir. **104**:241, 1916.

stitches were taken out. There was slight inflammation. Bronchopneumonia developed in the right lung. On the eleventh day, there was general urticaria. The wound was closed on the seventeenth day, and on the twenty-first day the patient was discharged. Three months later the right arm was paralyzed, the right pulse was absent and the aneurysm was healed. In February, 1909, the brachial plexus was operated on with partial return of function.

CASE 64[63] (surgeon, Kimura, 1908).—A patient, aged 46 years, was admitted to the hospital in September, 1908, and operated on for popliteal aneurysm. On October 12, a pulsating tumor, the size of a hen's egg, was found in the neck behind the right sternomastoid.

On November 20, with the patient under chloroform, an incision was made at the inner margin of the sternomastoid. The carotid was exposed, and the aneurysm was found to be of the bifurcation. The subclavian artery was ligated with two silk threads, and cut near its origin. The innominate was ligated and cut near the aorta. The common carotid, which had had a partial ligature placed on it, was then ligated tightly, and the aneurysm was partially removed.

On the first day after operation the patient was slightly hoarse; there were no motor or sensory disturbances, and no pulsation in the right radial artery. On the third day, the hoarseness disappeared; the dressing was changed. On the thirty-third day, the patient was discharged from the hospital. There were no disturbances of the brain or arm. Seventeen months after this, his general condition was good, except for slight difficulty in walking, resulting from the popliteal operation.

CASE 65[64] (surgeon, Ballance, 1909).—A white man, aged 35, was admitted to the hospital in 1909. He had a swelling at the right root of the neck, and this swelling increased in size. The right radial and the carotid pulsation were smaller than the left.

The first and second left costal cartilages, the inner end of the left clavicle and the left three fourths of the manubrium were removed. The aneurysm was near the bifurcation of the innominate. The origin of the vessel was normal. The tumor was ruptured as the ligature was passed. The innominate was plugged with a finger in the sac and ligated with two kangaroo tendon ligatures tied with a stay knot but not crushing the coats. The man died thirty hours later.

CASE 66[65] (surgeon, Sargent, 1909).—A woman, aged 67, was admitted to the hospital on Aug. 12, 1909; she had noted pulsation in the root of the right side of the neck for eight weeks. There were pain, loss of power in the right arm, dyspnea, occasional cyanosis and some precordial pain. On examination, there was a pulsating tumor above and lateral to the sternoclavicular joint. The right pupil was greater than the left. The right arm was weaker than the left. After three weeks' rest, the patient was better. She was seen by Dr. Ballance, and an operation was decided on.

On September 14, with the patient under chloroform, a median vertical incision was made. The anterior jugular was tied; the right half of the manubrium and part of the first costal cartilage were removed. The sternohyoid was separated from the tumor. The left innominate vein was exposed and pulled upward. The aortic arch and origin of the innominate artery were exposed and appeared normal.

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63. Imai: Ein durch Extirpation geheilter Fall von aneurysm der Art. Anonyma, Deutsche med. Wchnschr. **39**:1147, 1913.

64. Ballance (footnote 53, second reference).

65. Sargent: Aneurysm of the Innominate Artery, Proximal Ligature, Recovery, Lancet **1**:1200, 1911.

The innominate sheath was opened and a ligature passed ½ inch from the origin. Two thick floss ligatures were tied with a stay knot. Pulsation ceased. The carotid was tied through another incision at the cricoid cartilage with no. 2 silk. The wound was closed.

On the first day after operation the right side of the face and the arm were cold and pulseless. From the sixth to the ninth days, there was pulsation at the aneurysm. On the tenth day, weakness of the left arm and the left side of the face was noted. The patient was discharged at the end of three months with the facial weakness gone. In June, 1910, she was normal. No pulse was felt at the aneurysm, nor was there any weakness of the arm. The radial pulse was weak, but present. The pupils were equal. The patient died on Feb. 20, 1911, from bronchopneumonia and chronic nephritis.

Autopsy revealed pneumonia, pericarditis, chronic interstitial nephritis and arteriosclerosis. The aneurysm arose from the innominate artery; the ligature was half way from the aorta to the aneurysm and was represented by a groove and obliteration of the artery. No silk was found. The subclavian was obliterated half an inch short of the vertebral branch. The condition of the carotid could not be ascertained. The clots closing the vessels were inseparable from the walls. The collateral was through the vertebral, internal mammary, inferior thyroid and suprascapsular arteries, all of which were enlarged.

Case 67[66] (surgeon, Morf, 1911).—A white man, aged 55, was admitted to the hospital on May 20, 1911, with a history of pain for five or six years in the deltoid muscle and down the arm. While being treated by an osteopath, six months before admission, there was pain in the right supraclavicular region. The next day there was a pulsating tumor the size of a pigeon's egg. On admission, it was the size of a hen's egg and pulsated.

On May 28, with the patient under ether, an incision 13 cm. long was made 6 cm. above the clavicle. The sternomastoid muscle was divided. The inner third of the clavicle was resected. The right carotid artery was found and followed down to the innominate. The aneurysm involved the second portion of the subclavian. The innominate was isolated by blunt dissection. Two heavy kangaroo tendon ligatures were placed and tied. One ligature was tied about the common carotid at its origin. Pulsation ceased at once in the aneurysm and in the right arm. The wound was closed. The operation lasted one hour. The patient was in good condition.

After operation, the arm was slightly elevated and wrapped in wool. There was no cerebral disturbance. There was considerable pain in the right arm for a few days. The aneurysm became hard and firm. There was a distinct pulse in the right radial in two and a half weeks. Pulsation was felt in the aneurysm in three and a half weeks. The hand and arm were stiff for three months. In 1917, there was occasional pain in the right arm. The aneurysm measured 6 by 5 by 4 cm. The wall was firm and strong, except for a small area 2 cm. in diameter. It increased only slightly in size. The patient refused further operation.

Case 68[67] (surgeon, Ballance, 1911).—A white man, aged 43, was admitted to the hospital on Oct. 23, 1911, with a large pulsating swelling above the right clavicle, extending from the middle of the clavicle to the head of the bone and 2

66. Morf: Ligature of the Innominate Artery for Subclavian Aneurysm, Surg. Gynec. Obst. **25**:526, 1917.

67. Ballance: A Case of Ligation of the Innominate Artery for Subclavian Aneurysm, Proc. Roy. Soc. Med., Clin. Sect. **5**:99, 1912; footnote 53, second reference.

inches above the middle. The right radial pulse was feeble. The pulse in the carotid and in the temporals was equal on both sides. The right pupil was contracted. The larynx was normal. In a roentgenogram, the aneurysm was seen to obliterate the apex of the right lung.

On November 1, an oblique incision was made to expose the first part of the subclavian, and the aneurysm was found to involve this portion. The incision was continued to the midline to expose the innominate artery. The upper half of the manubrium was removed. The bifurcation of the innominate was low in the superior mediastinum. Two sutures of kangaroo tendon were placed around the innominate, which occluded without rupture, and were tied with a stay knot. The wound was closed.

After operation, pulsation ceased at once and did not return. There was no pulsation in the right arm, but it was never cold. At first there were numbness and tingling of the fingers of the right hand, and they were stiff. The right pupil was dilated for twenty-four hours; then it became contracted and remained so. The arm was massaged on the twelfth day, and the patient was up on the twenty-second. He was last seen one month after operation.

CASE 69[68] (surgeon, J. R. Morison, 1912).—A white man, aged 51, was admitted to the hospital with a pulsating swelling in the lower right side of the neck, extending from the midline to the deltoid. There was excruciating pain, with numbness and loss of sensation down the right arm, which was swollen and had enlarged veins.

On July 20, an incision was made along the anterior edge of the sternomastoid and out along the clavicle. The sternomastoid muscle was divided. An aneurysm was found to involve the second and third parts of the subclavian artery. The innominate artery was easily exposed and separated, except laterally, where it was adherent. A hole was accidentally made in the vessel because of disease. This was occluded with clip forceps. A thick silk ligature was then passed around the vessel below this opening. The vessel was occluded with thick silk ligatures, tied tightly above and below the opening. The right carotid artery was tied with thick chromic catgut. A piece of fascia lata from the thigh was tied about the vessels, and the wound was closed without drainage.

After operation, the pain disappeared. There was complete anesthesia of the right arm. Fourteen days later, the feeling returned. The wound healed by primary union. Six weeks later, a small bleb was opened, which drained serum; it closed two weeks later. When the patient was last heard of, in 1914, the condition of the arm had improved.

CASE 70[87] (surgeon, W. S. Halsted, 1912).—A colored man, single, aged 47, was admitted to the hospital on Oct. 18, 1912, with an aneurysm of the right subclavian artery of three and three-fourths years and eleven days' duration. The subclavian artery was ligated in July, 1909, by Mayo. The patient remained well until eleven days before admission, when the swelling was discovered again. There was a large tumor behind the inner end of the clavicle and the sternoclavicular joint, measuring 13 by 8.5 cm. No pulse was felt in the right axillary, brachial or radial arteries. The surface temperature of the right arm and hand was lower than that of the left. Function and sensation were normal. The right pupil was small and there was ptosis.

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68. Morison, J. R: Leaking Aneurysm of the Subclavian Artery: Ligature of the Innominate and the Right Carotid Artery, Brit. J. Surg. **1**:725, 1914.

On November 7, the right innominate artery was ligated for subclavian aneurysm. A faint pulsation in the aneurysm had returned by the time the wound was closed.

After operation the aneurysm became smaller, and measured 5.5 by 4 cm. on the discharge of the patient. No circulatory embarrassment of the hand was noted. The surface temperatures were about the same. At the last report, on Dec. 24, 1912, the patient had improved.

It was thought that this aneurysm was at the site of the previous ligation, and that the first aneurysm was in the third portion of the subclavian artery.

CASE 71[69] (surgeon, C. A. Hamann, 1913).—A white woman, aged 68, complained of severe pain in the right shoulder and arm and a pulsating swelling above the clavicle. The pain was present for from four to six weeks, and the swelling for one week. On Feb. 6, 1913, an attempt was made to insert a wire.

On February 10, with the patient under ether, an incision was made along the anterior border of the sternomastoid and along the clavicle. The sternomastoid was cut. The aneurysm was found to be of the third part of the subclavian extending to the first part. Two inches of the clavicle were resected. The innominate artery was exposed. A heavy braided double silk ligature was passed around the vessel ½ inch below the bifurcation and tied with an ordinary surgical knot. The coat of the vessel, which was atheromatous, gave way. Pulsation ceased at once. The common carotid was tied 1 inch from its origin with no. 2 chromic catgut. The wound was closed. A small drain was placed at the inner angle. The arm was wrapped in cotton.

After operation the wound healed by first intention. No pulsation of the sac was felt. There was no cerebral trouble. On June 29, little trace of the sac was felt, and there was no pulse in the radial or brachial arteries. Thirteen months after operation, the patient was in good health and working. No aneurysm or radial pulse was noted. There was slight paresthesia of the fingers and forearm. The blood flow reported by Stewart was as follows: On March 20, 1.5 Gm. per hundred cubic centimeters per minute in the right arm and 5.32 in the left, a ratio of 1:3.53; on March 21, 1.83 Gm. in the right arm and 6.38 in the left, a ratio of 1:3.48; on July 9, 8.26 Gm. in the right arm and 10.69 in the left, a ratio of 1:1.3

CASE 72[70] (surgeon, Thompson, 1914).—A colored man, aged 46, presented a large pulsating swelling of the axillary and supraclavicular spaces. For four days, his arm had been swelling. It showed a huge swelling with dilated veins and edema of the right arm. A constant boring pain in the hand and wrist was alleviated by raising of the shoulders. The radial pulse was absent. The heart was normal.

On June 23, 1914, a transverse incision was made 1 inch above the clavicle from the midpoint to the middle of the neck. The sternomastoid, sternohyoid and sternothyroid were divided. The carotids and the innominate were exposed; pressure stopped the pulsation in the sac. The innominate was ligated with narrow linen tape, two strips of tape side by side, with Ballance and Edmunds' stay knot.

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69. Stewart: Blood Flow in Hands and Feet in Cases in Which Obvious Anatomical Differences Exist, Arch. Int. Med. **12**:678 (Dec.) 1913. Hamann, C. A.: Ligation of the Innominate Artery with Report of a Successful Case, Ann. Surg. **59**:962, 1914; Ligature of the Innominate Artery with Report of a Case, Tr. Am. Surg. Assn. **32**:445 and 483, 1914.

70. Thompson, J. E.: Ligation of the Innominate Artery for Cure of Subclavian Aneurysm, Ann. Surg. **61**:641, 1915.

After operation there were no cerebral symptoms. There were complete paralysis and anesthesia of the arm. However, there was slight pain in the arm and shoulder. On July 15, more pain developed. On July 18, a soft, fluctuant tumor was felt in the floor of the right axilla. On July 21, pus was aspirated. On July 22, the axillary abscess was opened with a large flow of pus and blood. On August 1, there was a profuse hemorrhage from this site, which was packed. On August 29, sudden coma developed, and the patient died.

Autopsy revealed marked anemia in the brain. The heart valves showed ulcerations. The innominate artery was 5.5 cm. long; its wall was healthy. The left carotid rose from it; 2 cm. below the bifurcation above the left carotid was the ligature. The lumen of the artery admitted a small probe. The carotid distal to the ligature was normal. The aneurysm contained a clot. The distal opening was sealed.

Case 73[71] (surgeon, Lessnoi, 1915).—The patient was admitted to the hospital in November, 1914, shortly after being shot through the right side of the neck. There was a pulsating swelling toward the midline the size of a plum. Compression stopped the pulsation and also the pulse in the right carotid artery. Severe headache was caused by this. The radial pulse was equal. The patient was emaciated but normal, except for the tumor. After the wound healed, pressure was applied.

Operation was performed in January, 1915, general anesthesia being used. The head was dependent. An incision was made along the outer border of the sternomastoid to the manubrium, and the sternomastoid was cut. In clamping some of the vessels, the vagus was apparently caught, and the pulse ceased until the clamp was removed. An aneurysm of the common carotid was found. In an attempt to ligate the carotid it was found that the innominate was tied, as the pulse in the radial and carotid stopped. The aneurysm was therefore of the innominate. Excision of the sac was impossible. The wound was closed in layers with a small drain inserted at the lower corner.

After operation healing was uneventful. The drain was removed on the second day. Immediately after operation, the patient complained of headache, vertigo, difficulty in swallowing and weakness in the right arm. The right side of the face was cyanotic and pale. These symptoms disappeared in a short time, and the aneurysm disappeared. The patient was in good condition on discharge, except for loss of the carotid and the radial pulse.

Case 74[72] (surgeon, C. A. Hamann, 1915).—A colored man, aged 25, was admitted to the hospital on May 6, complaining of pain in the right shoulder and right arm of three weeks' duration. At this time a small lump appeared below the right clavicle. The lump increased in size rapidly till it measured from 3 to 4 inches in diameter; it was probably a subclavian aneurysm. There was loss of power in the right forearm and hand. No atrophy or edema was noted. The blood pressure in the right arm was 110 systolic and 88 diastolic; in the left arm, it was 130 systolic and 70 diastolic.

On May 11, the inner third of the clavicle was resected. The vessels were normal at the site of the ligature. The innominate was ligated with no. 5 braided silk and the common carotid with no. 3 chromic catgut.

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71. Lessnoi: A Case of Successful Ligation of the Innominate Artery, Arch. f. klin. Chir. **150**:280, 1928.

72. Hamann, C. A.: Ligature of the Innominate and Carotid Arteries for Subclavian Aneurysm, Cleveland M. J. **15**:221, 1916. Stewart: Studies on the Circulation in Man, J. Exper. Med. **22**:694, 1915.

After operation there was no cerebral trouble. The arm was warm. The wound healed by first intention, and the pain and weakness of the arm disappeared. Two months later the patient was in good condition. The tumor decreased in size and did not pulsate. The blood flow determinations were: three days before operation, 12.52 Gm. per hundred cubic centimeters per minute in the right hand and 6.36 in the left, a ratio of 2:1; eleven days after operation, 3.44 Gm. in the right hand and 15.38 in the left, a ratio of 1:4.47; seventeen days after operation, 4.76 Gm. in the right hand and 15.31 in the left, a ratio of 1:3.21; twenty-four days after operation, 4.86 Gm. in the right hand and 9 in the left, a ratio of 1:1.85; thirty-one days after operation, 8.55 Gm. in the right hand and 14.24 Gm. in the left, a ratio of 1:1.66. There was no pulse in the right hand at this time.

Case 75[73] (surgeon, Hamann, 1916?).—A woman, aged 59, had an aneurysm of the innominate, carotid and subclavian arteries. At the time of operation, the aneurysm was fusiform, and the three great vessels were dilated to three times their normal size. The innominate was tied with heavy silk and the carotid with chromic catgut.

After operation the patient developed a left-sided hemiplegia. She died on the fourth day.

Case 76[74] (surgeon, Coughlin, 1916).—A negro, aged 28, was admitted to the hospital on May 9, 1916, with an aneurysm of the right subclavian artery.

On May 18, with the patient under intratracheal ether, a midline incision was made from the upper margin of the clavicle downward for 4 inches. A transverse incision 1½ inches long was made at the upper and lower ends. The sternum and three upper costal cartilages of both sides were removed. The left innominate vein was exposed and drawn down. The innominate artery was exposed. An aluminum band was inserted, and the vessel was occluded one-half. The operation lasted one hour and fifteen minutes. There was considerable oozing on the right side of the incision.

Three weeks after operation, with the patient under local anesthesia, the incision was reopened. The innominate was tied just distal to the band, and the carotid was tied just below its bifurcation. Two years later the patient was living and cured of his aneurysm.

Case 77[75] (surgeon, T. Sinclair, 1916).—A white man was shot in the lower part of the right side of the neck on Aug. 24, 1916. He bled profusely for thirteen hours. He reached the casualty clearing station on August 25 and recovered from shock, but showed profound anemia. Traumatic arterial aneurysm developed in the lower part of the common carotid, which increased in size until the fourteenth day, when it measured 4½ by 4 inches. The wounds were suppurating. The patient was becoming hoarse from pressure on the recurrent nerve, and his temperature varied from 100 to 101.8 F.

On September 8, vertical and horizontal incisions were made. The sternomastoid was cut, and 1¼ inches of the clavicle was removed. The innominate was found behind the middle of the manubrium. It was tied with a single no. 4 chromic catgut ligature. The wound was closed over a small drain, which was

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73. Hamann (footnote 72, first reference).

74. Coughlin, W. T.: Removal of Portion of Sternum for Ligation of the Innominate Artery, Surg. Gynec. Obst. **26**:112, 1918.

75. Sinclair, T.: Ligation of the Innominate Artery for Traumatic Aneurysm of the Carotid, Brit. M. J. **1**:288, 1917.

kept in for forty-eight hours. The distal ligation was postponed because of the patient's condition.

The patient was discharged on September 16, eight days after the operation, with no infection. Three months after operation, examination showed no cerebral deterioration. These vessels in the right eye were slightly smaller than those in the left. No loss of vision or dizziness was present. The swelling had entirely disappeared. The pulse of the right radial and ulnar was absent. Some feebleness and stiffness in the hand were noted, probably due to prolonged disuse. Good pseudoarthrosis with the first rib gave motion to the arm and shoulder.

CASE 78[76] (surgeon, Coughlin, 1916).—A mulatto, aged 27, was operated on on Oct. 23, 1916, under local anesthesia. A median incision 4 inches long was made downward from 1 inch above the sternum. Three costal cartilages and the sternum were resected. When an attempt was made to pass a band behind the innominate artery, the vessel was ruptured, and the patient bled to death.

CASE 79[76] (surgeon, Makins, ——).—The patient was admitted to the hospital three days after a wound in the right side of the neck. He was pale and anemic, with a brachial monoplegia. There was no radial pulse. He was rested for fourteen days, and at the end of this time the tumor began to increase in size rapidly.

The innominate was exposed through an incision along the sternomastoid muscle, and a clamp was placed on it. The clavicle was resected, and a superficial blood clot was cleaned out. The aneurysmal sac was opened. There was an alarming hemorrhage, which was controlled by pressure against the cervical vertebra. The subclavian artery was found to be divided, and the hemorrhage occurred from the central end. The subclavian vein had apparently been destroyed. The first part of the subclavian artery was tied. The clamp was removed from the innominate artery.

The patient died at the end of three hours as a result of shock and hemorrhage.

CASE 80[77] (surgeon, Makins, ——).—The patient was wounded by a piece of shell which passed through the anterior border of the right trapezius muscle. There was marked hemorrhage at the time of the injury. Fourteen days later, there was a large subcutaneous swelling in the right side of the neck. This improved, and on the seventieth day operation was done.

An incision was made along the sternomastoid and along the clavicle. The sternomastoid was divided. The sac arose from the first portion of the subclavian artery and vein, and extended upward to the fourth cervical vertebra. The carotid and innominate arteries were exposed, and, owing to the injury to the first portion of the subclavian, a ligature was passed around the innominate and the third portion of the subclavian. The sac was dissected; during this process, it was opened by mistake. The innominate ligature was immediately tightened. The sac was found, dissected out and ligated off at its connection with the artery and the vein. The patient lost a considerable amount of blood. The wound was closed.

After operation, saline infusion improved the condition markedly. On the second day, there was a paralysis of the left arm, which disappeared on the fourth. The stitches were removed on the eighth day. From the seventh to twelfth days, there was discharge from the wound, which suggested an injury to the right lymphatic duct. The patient made an excellent recovery.

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76. Makins, G. H.: Gunshot Injuries to the Blood Vessels, New York, William Wood & Company, 1919, p. 181.

77. Makins (footnote 76, p. 184).

CASE 81[78] (surgeon, Sauerbruch, ——).—During the war, a small injury of the innominate artery was sutured by Sauerbruch. The patient died from suppurative mediastinitis five days later.

CASE 82[67] (surgeon, Halsted, 1918).—A colored man, aged 45, was admitted to the hospital on Jan. 28, 1918, with an aneurysm of the right common carotid artery of three years' duration. Pain was felt in the right sternoclavicular region. He had difficulty in swallowing. The right pupil was small, and there was slight ptosis. Behind the clavicle was found a tumor, 6.5 by 4.5 cm. The heart was normal.

On January 28, the innominate artery was ligated. The clavicle, part of the sternum and part of the first rib were resected.

The pulse was noted at the wrist in the afternoon of the operation, becoming countable at 8 p. m. A definite pulse was felt in the carotid and in the aneurysm, also in the wrist and the temporal artery, the day after operation. The blood pressure in the left arm was 122 systolic and 75 diastolic, and in the right arm 90 systolic and 67 diastolic. Ten days after operation, no pulse was felt in the aneurysm or the carotid; a good pulse was felt at the wrist. When the patient was discharged, the aneurysm was pulseless; the right pupil was small, and there was ptosis. A good pulse was felt at the wrist and in the temple. No cerebral disturbances or trophic or sensory changes were noted. On March 25, the patient returned to the hospital with a pulsation and an increase in the size of the tumor. The carotid artery was pulseless, but felt like a cord. The pulse in the radial and temporal was still felt. The blood pressure in the left arm was 105 systolic and 65 diastolic, and in the right arm, 83 systolic and 70 diastolic. On April 9, the common carotid was ligated with a band and ligature. The common carotid was small, thick-walled and contained no pulse, yet at the conclusion of the operation no pulse could be felt in the aneurysm. There was no return of pulsation in the aneurysm after this. On April 28, the patient was well. On May 6, the aneurysm was 5 cm. in diameter, and pulseless. The patient was last heard of on May 15, 1922, by letter. He works hard and shows no evidence of aneurysm. The aneurysm has disappeared, except for a small cord the size of the little finger.

CASE 83[67] (surgeon, M. Reid, 1918).—A white man, aged 45, with aneurysm of the innominate artery of two years' duration was admitted to the hospital on June 6, 1918. Severe pain was felt in the hand and occiput for two years before the swelling appeared. Ten months before admission, he had had the carotid and subclavian tied distal to the aneurysm, but with no relief. The pupils were equal. An aneurysm was eroding through the sternoclavicular articulation.

On June 15, an attempt was made to ligate the innominate artery for the aneurysm. The patient died before the ligature could be placed. Death was apparently due to pulling on the arch of the aorta. The innominate artery at its junction with the aorta was bigger than the aorta and was very sclerotic.

CASE 84[79] (surgeon, Halsted, 1918).—The patient had received a bullet wound in the right side of the neck above the sternoclavicular joint on Sept. 12, 1918. He walked one mile. Immediate swelling of the neck and hoarseness of the voice occurred, and there was hemoptysis for three days. He entered the base hospital on September 16, with a stiff neck, difficulty in swallowing and a weak and low voice. There was diffuse ecchymosis. Slight pain was felt.

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78. Krampf: Beitrage zur Gefaschirurgie, Deutsche Ztschr. f. Chir. **199**:152, 1926.

79. Halsted, W. B.: False Aneurysm of the Innominate Artery, Surg. Gynec. Obst. **30**:529, 1920.

Operation was performed on September 26. The patient was asphyxiated at the time he entered the operating room. An incision was hurriedly made over the most prominent part. There was a violent hemorrhage. The index finger inserted in the wound found the opening on the superior surface of the innominate artery. Clots were evacuated. The hemorrhage was controlled by a finger. The inner part of the clavicle and the upper part of the sternum were resected. The opening in the vessel was sutured with no. 0 chromic catgut.

The patient was up and around on November 10. He made gradual improvement.

CASE 85[64] (surgeon, C. A. Ballance, 1918).—A white woman, aged 60, was admitted to the hospital in December, 1918, with a pulsating tumor the size of an orange in the right side of the lower part of the neck, above the sternum and clavicle, extending to the superior mediastinum. Roentgen examination showed a normal aorta. The right arm, the carotid and the temporal pulses were weaker than the left.

On December 31, an incision was made in the midline of the manubrium meeting a transverse incision. Both flaps were dissected upward. The wall of the aneurysm was found to be weak. The left sternomastoid and the left upper half of the manubrium were cut; the sternoclavicular joint and the first costal cartilage were removed. The left innominate vein was exposed, and the origin of the innominate artery was found. It was ligated with two strands of kangaroo tendon without rupturing the coats, and tied with a heavy stay knot. The wound was closed in layers.

After operation, there was primary union. The right arm was cold and useless at first with no pulse and slight motion in the fingers. There was slight improvement at the end of six weeks, but no pulse. The aneurysm became small and solid. In January, 1921, two years after operation, dyspnea and palpitation were present. A small, hard mass could be felt behind the clavicle. There was no aneurysm. The right arm had recovered its usefulness. The right pulse was equal to the left. The patient was admitted to the hospital on December 12, with a cardiovascular breakdown, and died on June 6, 1922, with a large infarct of the lung.

Autopsy showed the aneurysm gone and the artery obstructed. A fibrous mass was left attached to the distal part of the artery.

CASE 86[80] (surgeon, Juckelson, 1919).—The patient, aged 30, had been injured in the outer margin of the left side of the neck with a dull instrument some time before admission. On examination, a pulsating mass was seen near the midline, adherent to the clavicle. There was ptosis on the left. A diagnosis was made of aneurysm, either of the carotid or of the subclavian artery on the left.

On April 14,1919, an incision 18 cm. long was made along the right sternomastoid muscle. The aneurysm burst. The bleeding was stopped with the finger. The inner end of the clavicle and of the sternum were removed. The source of the bleeding was traced down to the artery and the first part of the common carotid was found to be involved. There was considerable fibrosis of the tissues. The innominate artery was ligated twice, 1.5 cm. apart. The finger was removed, but bleeding continued from the distal side. The common carotid and the subclavian were also ligated. The sac consisted of two parts. The one projecting to the left side and filled with clot did not pulsate. Part of the sac was removed, but it was necessary to stop, and the remainder was packed. Removal of pressure on the trachea improved the patient's breathing.

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80. Juckelson: Case of Ligation of the Innominate Artery, Zentralbl. f. Chir. **13**:687, 1925,

The postoperative course was uneventful. The wound healed where it was sutured excellently. Except for a left-sided headache, there were no brain symptoms. Slight paleness of the right arm was noted. The radial pulse did not return. The patient was discharged two weeks after operation with a granulating wound. Five years and eight months after this he was in good health, and did not have an aneurysm.

CASE 87[81] (surgeon, Hertzler, 1922).—The patient was injured on Dec. 25, 1921, by a gunshot wound from the top of the sternum to the right shoulder. The bullet was removed from the right shoulder. Immediate paralysis of the right arm developed. The pulsating mass appeared in the right supraclavicular fossa. The mass was the size of an orange. A diagnosis of aneurysm of the right subclavian artery was made.

On Nov. 24, 1922, with the patient under ether, an incision was made along the right clavicle. The sternomastoid was resected. A large sac was found extending to within 1 cm. of the innominate. The innominate was ligated with double linen thread, just below the bifurcation. The wound was closed with an iodoform gauze drain. The patient was discharged one month later, after uneventful recovery. There was no pulsation in the aneurysm; no pulse was felt in the right arm. The paralysis was better. Ten days later, pulsation returned in the sac. On Jan. 13, 1923, with the patient under local anesthesia, the vertebral and common carotid were ligated. Pulsation did not cease entirely. Recovery was uneventful. On June 16, an aneurysm the size of an egg was still present and pulsating. Pulsations were present in the right radial and ulna.

CASE 88[82] (surgeon, Holman, 1922).—A white man, aged 25, on Oct. 22, 1922, sustained a pistol shot in the right clavicular region. A profuse hemorrhage was easily controlled by slight pressure. Several days later, he noticed a small tumor about 2 cm. above the small healing wound. It progressed slowly for five weeks, and rapidly after that. After the accident, he noticed violent beating of the heart when he made the slightest effort. He was admitted to the hospital on November 29, with a large pulsating swelling extending from the midline to the anterior border of the trapezius. There was a small scar at the site of the wound. The bullet was near the apex of the left lung. Thrill and murmur were continuous. Deep pressure above the center of the clavicle caused both to disappear and caused a temporary slowing of the pulse. Release of pressure caused a momentary rapid beating of the heart. The blood pressure in the left arm was 108 systolic and 62 diastolic. After compression, it rose to 114 and then fell to 108. On release of pressure it fell to 102 and recovered immediately to 108. On release of the pressure, the diastolic pressure fell to 48, recovering within a few seconds to 62. The blood pressure in the right arm was consistently from 4 to 8 mm. less than in the left. The superficial veins of the forearm were more prominent on the right than on the left. There was no cardiac enlargement. A diagnosis of varicose aneurysm of the subclavian vessels with a small communication was made. Operation was planned to expose the subclavian vessels and to ligate with quadruple ligature.

In December, 1922, along the clavicle to the sternum, a horizontal incision was made which bisected a median vertical incision. Two thirds of the clavicle was

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81. Hertzler, A. E.: Traumatic Aneurysm of the First Part of the Subclavian Artery, S. Clin. N. Amer. **3**:1507, 1923.

82. Holman, E.: Surgery of the Large Arteries with Report of a Case of Ligation of the Innominate Artery for Varicose Aneurysm of the Subclavian Vessels, Ann. Surg. **85**:173, 1927.

resected, and the clavicle was slightly eroded. When the clavicle was removed the aneurysm burst, sending out a flow of arterial and venous blood under great pressure. This was stopped by pressure with the thumb, and the clavicle and sternum were resected. The innominate artery was exposed and a tape ligature was placed around it with a small length of rubber tubing to prevent crushing the wall. The common carotid was exposed and occluded in a similar manner. The pulsation of the swelling ceased, and the operation could be continued. Rows of silk sutures closed the sac. The carotid ligature was released with bleeding. The innominate ligature was released with return of pulsation and bleeding. Therefore permanent tape ligature occluding the innominate artery, but not crushing it, was applied. The wound was closed without drainage. The patient was in a poor condition.

The subclavian vein was probably included in the deep sutures, which explained the cessation of thrill and bruit. Marked pallor and absence of perspiration on the right side of the face were noted immediately after operation. Right radial paralysis returned eight hours after operation. There was some numbness of the right arm and hand, which disappeared in forty-eight hours. Four days after operation, the neck was normal in size, and there was no pulsation. Thirteen and twenty days after operation, a small opening along the line of incision was made to evacuate old fluid blood. At discharge, a good pulse could be felt at the wrist, and the right carotid and temporal vessels felt full and firm. The veins in the left arm collapsed 4 degrees above horizontal, and in the right arm 20 degrees above horizontal. This was interpreted as indicating that the subclavian vein had been occluded at operation. The blood pressure in the right arm was 76 systolic and 74 diastolic, and in the left arm 120 systolic and 76 diastolic. One year after operation the right arm was still weaker than the left but was gradually improving. There was no perspiration on the right side of the face. The right side of the face and the right arm were colder in cold weather. Slight enophthalmos was present. The pupils were equal. The neck was normal. The right carotid and the radial pulse were weak and slightly retarded. There was no atrophy. The blood pressure in the left arm was 118 systolic and 92 diastolic, and in the right arm 90 systolic and 70 diastolic.

Case 89 (surgeon, Greenough, 1924).—This case was reported in full in the beginning of this article.

Case 90 [83] (surgeon, Sauerbruch, 1925).—On Jan. 19, 1925, operation was performed on a partly calcified tumor reaching into the upper thoracic aperture. The inferior and superior thyroid arteries were ligated. In dissecting the lower pole, a severe arterial hemorrhage occurred. The vessel was inaccessible, so compression controlled the hemorrhage. Part of the manubrium was resected, and the bleeding was found to come from a short thyroidea ima springing from the innominate just before bifurcation. Rubber clamps were applied to the innominate. With fine button silk sutures, a longitudinal suture 1 cm. long was made of the contused part of the innominate, including the origin of the thyroidea ima. When the clamps were removed there was no hemorrhage, although the artery was somewhat narrowed. The operation proceeded; the wound was closed in the usual manner. The postoperative course was uneventful.

Case 91 [83] (surgeon, E. R. Flint, 1927).—A white man, aged 37, had a bullet wound at the base of the right side of the neck nine years before admission to the

83. Flint, E. R.: Ligature of the Innominate Artery for Innominate Aneurysm, Brit. M. J. **1**:979, 1928.

hospital. After the wound healed two swellings were left, and the voice remained husky; there were frequent attacks of pain in the neck, headache and vomiting. There had been transitory loss of vision in the right eye two years before. Two weeks before admission the swelling over the manubrium had increased rapidly with an increase in pain and difficulty in swallowing; the right pupil had become smaller than the left. In the right radial and carotid arteries there was only weak pulsation. There was paralysis of the recurrent nerve.

On Jan. 24, 1927, the manubrium sterni was removed after the sac had been carefully dissected off. The aneurysm of the innominate was found at the bifurcation. There was ½ inch of normal artery proximal to this. A ligature of no. 2 chromic catgut was passed and tied sufficiently tight to approximate the walls. The recent symptoms had probably been due to a leak which was found in the upper right side of the sac. The clot was turned out. There was vigorous bleeding from the subclavian artery. The inner side of the sac was sutured at this point and the hemorrhage stopped. The sac was packed, as it was impossible to remove or obliterate it.

The wound took some weeks to heal owing to the packing. The right arm was useless at first, but later improved and was stronger; it remained pulseless. At the end of six months, the patient was well. There has been no recurrence of aneurysm. The patient still had a husky voice and vision was limited to the central area.

SUMMARY

A case of successful ligation of the innominate, carotid and subclavian arteries is reported.

Ninety-one cases of operation on the innominate artery, 75 per cent of which were ligation, are collected from the literature and summarized.

The total mortality after ligation is 56 per cent.

The mortality in the last 25 cases is 16 per cent.

Sufficient exposure by bone resection is advisable in operations on the innominate artery.

The innominate should be ligated with strong material applied with a force between 3 and 10 pounds (1.4 and 4.5 Kg.), and a stay knot used and the artery severed.

The wound, if uninfected, should not be drained.

If the operation is for aneurysm, distal as well as proximal ligation should be done and the sac extirpated or destroyed.

It is more advisable to ligate the subclavian artery than the carotid.

Ligation of the right innominate vein should benefit the circulation in the brain and the upper extremity.

The operation is justifiable, and if contemplated should be done early.

BIBLIOGRAPHY

Eve: History of the Ligature Applied to the Innominate Artery with Statistics, Nashville J. M. & S. **11**:1, 1856.

Power: Anatomy of the Arteries, Philadelphia, J. B. Lippincott Company, 1863.

Sabine: Treatment of Aneurysms, Am. Med. Times **9**:74, 89, 101 and 116, 1864.

Hargrave: Reflections on the Operation for Securing the Arteria Innominata with Suggestions for a New Operation, Med. Press & Circ. **1**:223, 1868.

Koch: Statistics on Aneurysm, Arch. gén. de méd. **2**:213, 1869.
Poland: Statistics of Subclavian Aneurysm, Guy's Hosp. Rep. **15**:47, 1869; **16**: 1, 1870; **17**:1, 1871.
Lane: Ligations Done for Cure of Subclavian Aneurysm, Pacific M. & S. J. **26**: 145, 1883.
Senn: Experimental Researches on Cicatrization in Blood Vessels after Ligature, Tr. Am. Surg. Assn. **2**:249, 1884.
MacCormac: Surgical Operations: Ligature of Arteries, London, Smith, Elder and Company, 1885, p. 72.
Bardenheuer: Osteoplastic Resection of the Sternum, Mitt. a. d. Kölner Bürgerhosp., 1886, vol. 1.
Spencer and Horsley: Report on Control of Hemorrhage from the Middle Cerebral Artery and Its Branches by Compression of the Common Carotid, Brit. M. J. **1**:457, 1889.
Wyeth: Aneurysms of the Third Portion of the Right Subclavian Artery, Internat. J. Surg. **3**:237, 1890.
Ballance and Edmunds: Treatise on Ligature of Great Arteries in Continuity, London, 1891.
Souchon: Operative Treatment of Aneurysms of the Third Portion of the Subclavian Artery, Am. J. Surg. **22**:545 and 743, 1895.
Guinard: Traitement des anéurismes de la base du cou, Ann. de mal. de l'oreille, du larynx **22**:393, 1896.
Milton: Mediastinal Surgery, Lancet **1**:872, 1897.
Removal of Foreign Body from the Bronchus by Intrathoracic Tracheotomy, Lancet **1**:242, 1901.
Savariaud: The Surgical Treatment of Aneurysms of the Subclavian Artery, Rev. de Chir. **34**:1, 1906.
Gordano: New Procedure for Ligation of the Innominate, Gazz. d. osp. **27**:209, 1906.
Solari: Surgical Treatment of Aneurysms of the Innominate Artery, Montpel. méd., 1906.
Galliard: Aneurysms of the Innominate Artery, Bull. et mém. Soc. de chir. **24**: 1121, 1907.
Imbert and Pons: Innominate Aneurysms, Arch. prov. de chir. **16**:445 and 555, 1907.
Wolff: The Incidence of Gangrene of the Extremities After Ligation of the Great Vessels, Beitr. z. klin. Chir. **58**:762, 1908.
Guinard: Treatment of Aneurysms of the Base of the Neck, Rev. de chir. **39**: 229, 1909.
Matas: Testing the Efficiency of the Collateral Circulation as a Preliminary to the Occlusion of the Great Surgical Arteries, Ann. Surg. **53**:1, 1911.
Rubritius: The Surgical Treatment of Aneurysms of the Subclavian Artery, Beitr. z. klin. Chir. **76**:144, 1912.
Barling: The Surgical Treatment of Aneurysm, Proc. Roy. Soc. Med., Surg. Sect. **5**:159, 1912.
Walther: Aneurysm of the Carotid, Bull. et mém. Soc. de chir. **41**:1975, 1915.
Soubbotitch: Some Considerations on Traumatic Aneurysms, Bull. et mém. Soc. de chir. **42**:698, 1916.
Tilman: Operations on the Innominate and Left Carotid Arteries, Zentralbl. f. Chir. **43**:689, 1916.
Symonds: Traumatic and Arterio-Venous Aneurysms, Lancet **1**:576, 1917.

Sencert: Wounds of the Great Vessels at the Base of the Neck, J. de chir. **15:** 101, 1919.

Matas: Some Experiences and Observations in the Treatment of Arterio-Venous Aneurysms, Ann. Surg. **71:**403, 1920.

Hertz: Arterial Ligatures and Sutures, Arch. de mal. du coeur **16:**216, 1923.

Brooks and Martin: Simultaneous Ligation of Vein and Artery: An Experimental Study, J. A. M. A. **80:**1678 (June 9) 1923.

Holman: Arterio-Venous Aneurysm, Clinical Evidence Correlating Size of Fistula with Changes in Heart and Proximal Vessels, Ann. Surg. **80:**801, 1924.

Experimental Studies in Arterio-Venous Fistulas: I. Blood Volume Variations, Arch. Surg. **9:**822 (Jan.) 1924.

Reichert: An Experimental Study of the Anastomotic Circulation in the Dog, Bull. Johns Hopkins Hosp. **35:**385, 1924.

Horsley: Healing of Arteries After Different Methods of Ligation, J. A. M. A. **85:**1208 (Oct. 17) 1925.

ABSTRACT OF DISCUSSION

Dr. John Alexander, Ann Arbor, Mich.: A year ago I had occasion to perform decompression on the superior mediastinal organs for suffocation from a slowly dissecting ruptured aneurysm of the aortic arch. Good, strictly extrapleural exposure of the arch of the aorta, the innominate artery and vein was obtained under local anesthesia after resecting the second right costal cartilage and anterior end of the second rib, the lower part of the first costal cartilage and the upper part of the second, and the right half of the manubrium; the internal mammary vessels were ligated and divided, and the pleura rolled laterally and posteriorly. An innominate artery that was normal at its origin might have been ligated without great difficulty. Another operation on the right superior mediastinum also demonstrated the usefulness and relative simplicity of this approach.

Dr. Emile Holman, San Francisco: If you are encouraged by Dr. Greenough's interesting presentation to ligate the innominate artery, I think that you would be wise to ligate the innominate vein also.

I recently operated on a patient with a subclavian aneurysm. The subclavian, the carotid and the axillary arteries were ligated distal to the aneurysm, and I also ligated the innominate vein. Gangrene was averted, I feel, by the ligation of the vein. In case you are prompted to proceed with multiple ligations, I think that the innominate vein should be ligated also. It is not quite clear as to whether Dr. Greenough ligated the carotid and subclavian distal to the aneurysm or proximal to it.

Dr. James Greenough: The arteries were ligated distal to the aneurysm.

The subclavian approach from behind is, of course, simple in the operation of thoracoplasty of the first rib, but one is doing a great deal of operating for another purpose. I think that if one is going to ligate only the subclavian or the innominate, the anterior approach would be easier.

The anatomy of the origin of the innominate, and of the bifurcation varies considerably, and I think that this variation determines the question of whether the thorax has to be entered or not.

OPERATIONS AND DEMONSTRATIONS OF CASES IN BARNES HOSPITAL

1. THORACOPLASTY AND PHRENICECTOMY

EVARTS A. GRAHAM, M.D.
AND
DUFF S. ALLEN, M.D.
ST. LOUIS

CASE 1.—*Phrenicectomy for Bronchiectasis of the Left Lower Lobe by Dr. Graham.*

A woman, aged 28, was admitted to the hospital on Nov. 13, 1928. Her chief complaint was bloody expectoration of fifteen months' duration, most marked during the three weeks previous to admission. She had always been weak and susceptible to colds. She had whooping cough at the age of 5 years and mumps at the age of 12. Her menstrual history was negative. She had been married for eight years, but there had been no pregnancies.

The onset of the present illness occurred at the age of 13, when the patient suffered from a cold which was associated with a purulent discharge from both ears. Her cough was then productive of grayish-white sputum. She was able to be up and about, however, and it was not until the age of 16 that she contracted what was considered to be typical pneumonia of the left lower lobe. Shortly after her recovery from this condition she had her tonsils and adenoids removed and from this time on she was no longer troubled with earache or discharging ears. Her cough disappeared and did not return until she suffered from another attack of pneumonia at the age of 18. The pneumonia also apparently cleared up and she was well until the age of 21 when the cough and expectoration returned as before. Since then she has been gradually losing weight. During the fifteen months previous to her admission to Barnes Hospital she coughed up blood in amounts up to a cupful.

On admission, the blood count showed a slight secondary anemia, and a leukocytosis of 13,000. The differential count was normal; the sputum showed no tubercle bacilli. The Wassermann and Kahn tests of the blood were negative. Physical signs and roentgen examination indicated a lesion in the left lower lobe considered to be bronchiectasis (fig. 1). Because of an alarming hemorrhage, bronchoscopy was not performed and patient received pneumothorax treatment on the left side. She is still receiving this treatment and has undoubtedly improved.

She was readmitted to the hospital on April 24, 1929, because it was thought that a phrenicectomy might improve her condition further by elevating the lower lobe and thus making the dilated bronchi more horizontal and less dependent. This operation was performed on April 25. With the patient under procaine hydrochloride infiltration anesthesia an incision was made parallel to and about one-half inch (1.27 cm.) above the left clavicle. The sternocleidomastoid muscle was split in the direction of its fibers immediately over the scalenus anticus muscle. The phrenic nerve was found in its normal position on the anterior border of the latter muscle. The nerve for a distance of about 12 inches (30.4 cm.) was twisted out of its bed. A little nitrous oxide was given to the patient while the nerve was being twisted.

The patient's diaphragm was observed to be paralyzed on the following day, and since then it has risen further. Pneumothorax treatment is being continued, and she has undoubtedly improved appreciably. It has been thought advisable to treat the nasal sinuses, but in this instance it was felt that the other procedures noted could perhaps be performed first with advantage.

CASE 2.—*First Stage Extrapleural Thoracoplasty for Tuberculosis, by Dr. Graham.*

A woman, aged 39, was admitted to Barnes Hospital on July 5, 1928. Her chief complaints were productive cough, weakness and vomiting.

Fig. 1.—Bronchiectasis of the left lower lobe demonstrated by injection of iodized oil. The oil seen in the extreme lower portion of the left side is in the stomach and not in the lung.

At the age of 15 the patient suffered from pain in the left side of the chest but it was not until 1922 that she had what has been described as an attack of influenza. She then began to suffer from elevation of temperature. Tubercle bacilli were found in the sputum at that time. Since then she has also had frequent attacks of pain in the left side of the chest, productive cough and fever, and has been losing weight. She has had hemorrhages on several occasions and of late some vomiting.

On admission, the leukocyte count was 18,600; physical signs verified the diagnosis of left-sided chronic pulmonary tuberculosis with cavitation (fig. 2). She was discharged from the hospital on July 17, 1928, and was readmitted on September 28.

Her condition on this occasion did not show any obvious improvement and it was thought advisable to start pneumothorax treatment. The sputum was negative. The first pneumothorax treatment was given on October 2, and this form of treatment was continued at intervals but not with any marked improvement since there were several adhesions extending from the midportion of the lung to the wall of the chest.

Cauterization of the pulmonary adhesions through a thoracoscope was therefore attempted on October 29, but this was only partially successful since many of the adhesions were broad and of the type that is best left alone. This procedure was not followed by any particular discomfort and the patient was discharged on November 30. She was readmitted to the hospital on Feb. 27, 1929.

Fig. 2.—Left unilateral pulmonary tuberculosis before operation.

Twelve inches of the phrenic nerve on the left side were removed on March 2. This operation was followed by some rise of the diaphragm but it was obvious that a thoracoplasty was indicated. It was performed in two stages: the first one on April 25 when portions of four lower ribs from the transverse process to the midaxillary line were removed. The patient stood this operation well but not until May 8 were the remaining ribs, including the first, removed. The postoperative course was satisfactory. Suppurative otitis media developed, but this was apparently not of a tuberculous nature. She was discharged on June 16, much improved (figs. 3 and 4). At her most recent admission on September 29, the following notes have been made: The patient feels well and looks well. She has gained in strength, is able to do light work and no longer has gastro-intestinal discomfort. She is free from cough and expectoration and is up and about.

CASE 3.—*Thoracoplasty for Chronic Suppurative Empyema, by Dr. Graham.*

A man, aged 65, was admitted to Barnes Hospital on Feb. 6, 1929. He complained of pain in the left side of the chest, loss of weight (from 145 to 129 pounds), 16 pounds (7.8 Kg.) in two months, and of weakness. He had pneumonia in 1903, and questionable pleurisy in 1907. The present illness began on Dec. 1, 1928, when the patient was taken ill with a chill, pain in the left side of the chest and coughing. He was then considered to be suffering from pneumonia. He was taken to a hospital, where he remained for eight weeks. His course in this hospital was not suggestive of a simple pneumonia and because of failure to improve he came to Barnes Hospital on Feb. 6, 1929, suffering from the foregoing complaints.

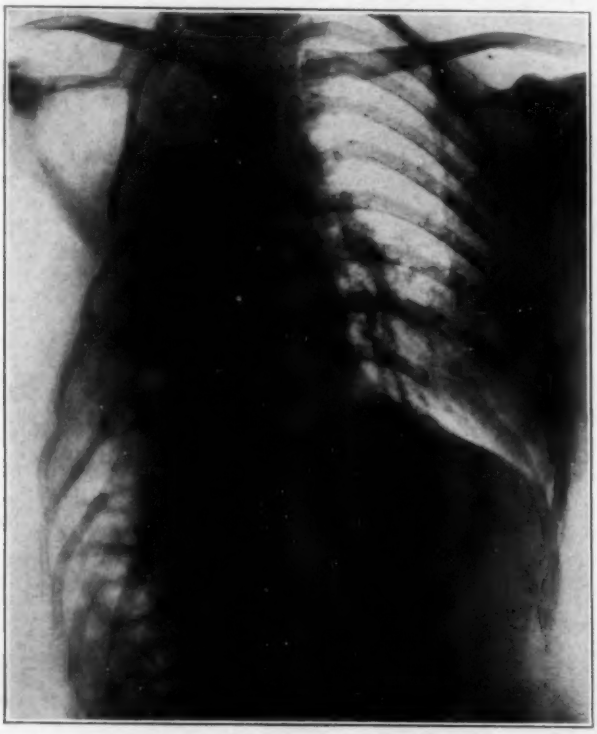

Fig. 3.—The same case as figure 2 after the completion of the thoracoplasty. A thoroughly satisfactory collapse of the left side was obtained by the operation.

The physical signs and roentgenograms showed a left-sided encysted empyema (figs. 5 and 6). The patient's prostate was slightly suggestive of a malignant condition. No tubercle bacilli could be demonstrated in his sputum. On February 12, a portion of the fifth left rib was resected between the posterior and anterior lines. About 250 cc. of thick, odorless pus escaped. There were also several large masses of fibrin. The parietal pleura was not so much thickened as would be expected in an ordinary empyema. A piece of the pleura was removed for microscopic examination and was subsequently reported as chronic inflammatory tissue. Two large tubes were inserted for drainage. Into each was passed a Dakin tube for irrigating purposes. The postoperative course was fairly satisfactory, but the cavity never became completely obliterated.

Because of the persistence of a small cavity and some bronchial fistulas, the patient was again operated on on April 25. The incision was carried around the old sinus. The old empyema cavity was found to extend backward and both upward and downward along the vertebral gutter. Two more ribs and thickened parietal pleura were resected in order to take off part of the roof of the cavity. It was not certain whether the foregoing procedure would suffice, but it was thought unwise to prolong the operation any longer because of the patient's advanced age. A piece of pleura was again removed for examination and showed nothing but chronic inflammation. The postoperative course was satisfactory and the patient would have been discharged much earlier than June 25, had it not been for the fact that he was suffering from a frequency of urination due to prostatic hypertrophy.

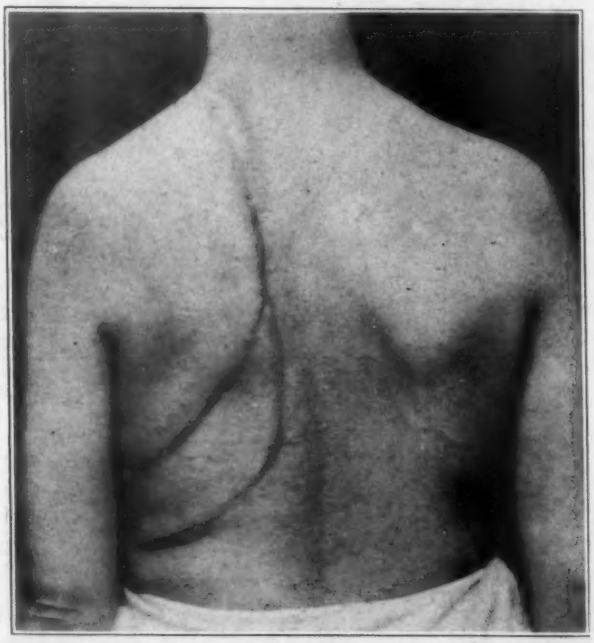

Fig. 4.—The same patient showing healed incisions. Sometimes we perform both stages of a thoracoplasty through the same incision. For the second stage the first incision is reopened. Lately, however, we have been employing two incisions as shown in the illustration. These have been retouched on the photograph to make them more visible.

It is to be noted that an injection of iodized oil demonstrated the presence of a left-sided bronchiectasis of the saccular type so that the possibility that one of these sacculations had broken into the pleura could not be excluded.

The patient's wound healed solidly, and in September he reported that he had no symptoms attributable to his old empyema.

CASE 4.—*Thoracoplasty for Tuberculous Empyema, by Dr. Allen.*

A man, aged 48, was admitted to Barnes Hospital on April 24, 1929. The onset of the present illness was somewhat indefinite. In February, 1928, he complained of night sweats and fever but did not suffer from cough or hemoptysis. He then entered the City Hospital only to be transferred to Koch Hospital where he remained for one year and where his condition was diagnosed as chronic pulmonary

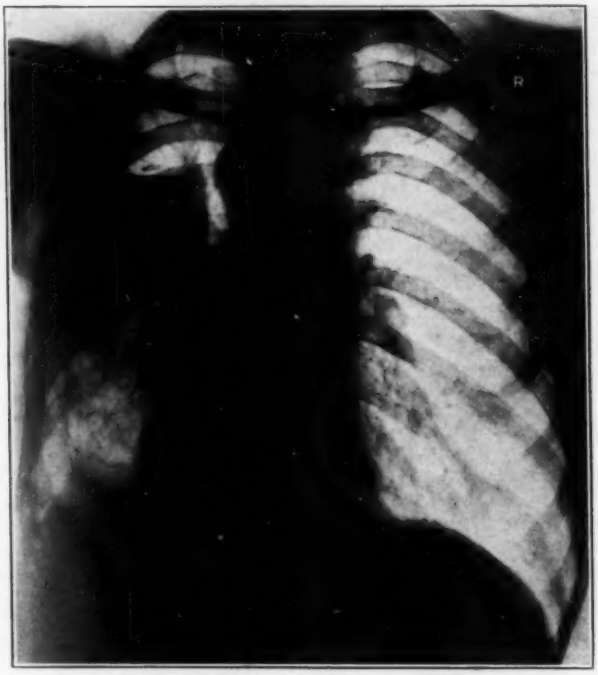

Fig. 5.—Old encysted empyema.

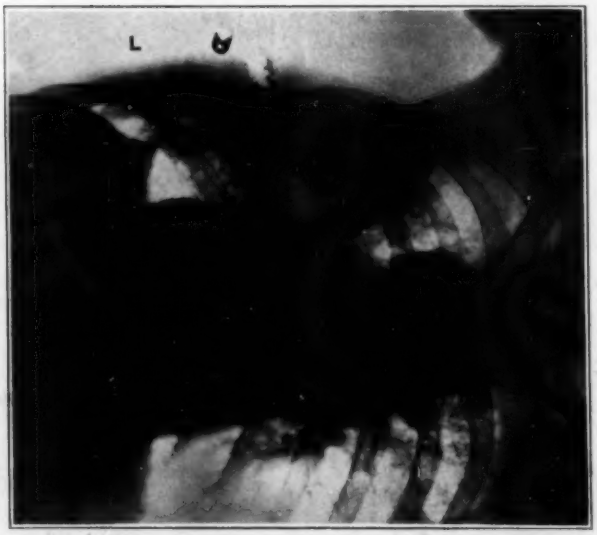

Fig. 6.—Injection of iodized oil through the external fistula in the same case as in figure 5.

tuberculosis of the right lung. He began to suffer from pain in the right side of the chest which necessitated a resection of the ribs in September, 1928, when a diagnosis of right-sided empyema was made. He returned to the City Hospital in February, 1929, because of cough, expectoration and discharging sinuses of the chest. The sinuses, however, were troubling him more than the cough and expectoration. A thoracoplasty was performed in several stages; the first at the City Hospital, the second on April 25, and the last stage on June 8. The intervals between the various stages were long because the postoperative course in every instance was rather stormy.

The patient is continuing his rest cure at the present time. He feels much improved and is no longer troubled with discharging sinuses.

2. CLINIC DEMONSTRATIONS

JACOB J. SINGER, M.D.
AND
EVARTS A. GRAHAM, M.D.
ST. LOUIS

It is our desire to present a series of cases which illustrate not only certain interesting conditions but also certain details of our methods of handling such cases here. We also wish to emphasize the importance of an approach to all cases of chest conditions according to a plan of cooperation between the medical and surgical services. For nearly ten years we have been associated in the organization and development of a chest service for this group of hospitals. We meet almost daily and discuss patients who may possibly have any surgical conditions of the chest. The mutual cooperation of those with a medical and those with a surgical point of view on many of these cases is most helpful. In any large general hospital there are many patients who too often remain in the medical wards and are not given the benefit of the possibility of surgical help. The organization of a chest service for diagnosis and discussion of this group of patients will do much to increase the amount and improve the quality of thoracic surgery at that institution.

ABSCESS OF THE LUNG

The first group of cases which we shall present is a series of abscesses of the lung. We have recently noted a sharp decline in the number of such cases and also of bronchiectasis. It is interesting to note on inquiry that many others have also made this observation. Whether the warnings of this association of the dangers of tonsillectomy performed under general anesthesia are responsible for this decline, we do not know. Probably other factors are operating, such as no repetitions of any epidemic of respiratory disease corresponding to the influenza epidemics of 1917 and 1918.

We have consistently attempted to treat our patients in a conservative way, waiting for several weeks before employing any surgical procedure. We, like others, have found that many abscesses, although very large, will heal in time merely by the use of postural drainage.

The abscesses in many patients who seem suitable subjects for bronchoscopic drainage, according to the report of our leading bronchoscopists, have been healed in a few weeks without it. For this reason we are probably more conservative in our opinion of, and perhaps even more skeptical about, the therapeutic value of the bronchoscope in this type of case than are many others. As a matter of fact, in our experi-

ence the type of case which responds most readily to bronchoscopy is the same as that which also responds best to postural drainage or to methods of collapse.

In almost no case do we resort to surgical measures until after trial of the comparatively simple methods of postural drainage alone or of that combined with pneumothorax when the latter is possible. We also agree with Miller and Lambert and others that it is very dangerous to induce surgical drainage during the acute stage of a pulmonary abscess at a time when it is necessary to traverse a large zone of edematous lung tissue in order to reach the abscess.

CASE 1.—*Acute Abscess of the Lung Treated with Postural Drainage.*

G. C., a man, aged 49, was admitted to the hospital on June 7, 1927, complaining of chills, fever, cough, mucopurulent expectoration and general malaise. The onset of symptoms was six days after a tonsillectomy, three weeks previous to his admission to the hospital. Physical and roentgen examinations revealed the presence of an annular cavity about 5 cm. in diameter in the region of the hilum of the right lung. This cavity showed a fluid level which shifted with change of position. The patient's sputum contained many spirochetes.

Treatment consisted only of postural drainage and six intravenous injections of neoarsphenamine at weekly intervals. Improvement was gradual but definite. After two months the shadow at the site of the abscess had almost entirely disappeared, and the patient has been entirely free from all symptoms since then, nearly two years (figs. 1 and 2).

This case illustrates in a striking manner the healing after simple treatment of a large acute abscess of a kind which is usually subjected to more formidable measures, such as surgical drainage, pneumothorax or even bronchoscopic drainage.

Surgical drainage is instituted only after a trial of various medical means including bronchoscopy, pneumothorax, postural drainage and intravenous medication of arsenic in the cases of spirochetal infection. We usually wait from five to six weeks in acute cases before considering surgical drainage, and we wait even longer if the progress with more conservative measures seems satisfactory. In the chronic cases the location of the abscess, the presence of adhesions and the general condition of the patient determine our course. As a result of the more extensive use of conservative measures in the treatment of acute pulmonary abscess during the last five years we now operate much less often in such cases than formerly.

In spite of all methods of treatment, however, some cases become chronic and refractory. The following case is illustrative of the type in which we think the operation of cautery pneumectomy is indicated. Probably no other method known at present would have been so safe and at the same time so effective in ridding this patient of multiple abscesses.

Fig. 1.—Abscess cavity in the right lung in case 1 of clinic demonstrations.

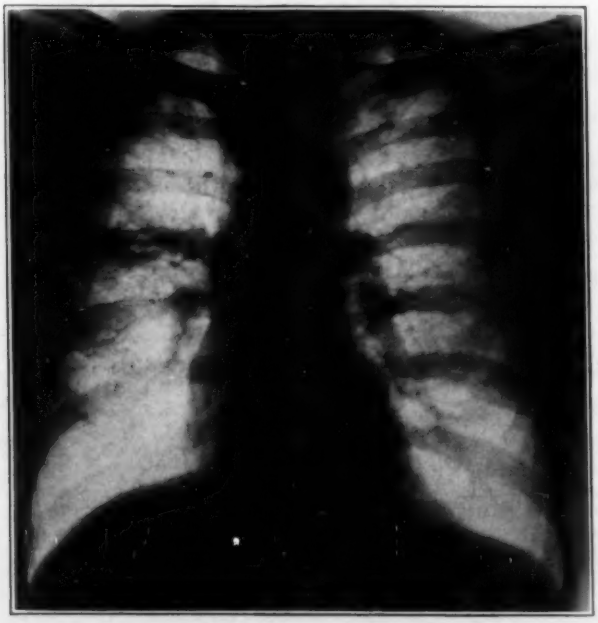

Fig. 2.—Same case as in figure 1, seven months later, showing complete healing of the abscess cavity produced only by rest and postural drainage.

CASE 2.—*Cautery Pneumectomy for Chronic Multiple Abscess of the Lung.*

L. P., a man, aged 28, was admitted to Barnes Hospital on Sept. 13, 1926. His complaints on admission were cough, expectoration and weakness. Five months previously to admission his tonsils were removed elsewhere under ether anesthesia. Three days after the tonsillectomy he noticed a slight dry cough which continued to increase in severity and became very productive. His appetite became poor, and he lost 18 pounds (8.2 Kg.) in weight during the three months before admission. He also complained of slight pain under the right shoulder and of fever during his entire illness.

On admission, physical examination showed that all the physical signs in the chest were localized to the region of the right hilum where breath sounds were diminished. An injection of iodized oil showed no direct evidence of any abscess cavities.

Artificial pneumothorax with repeated refills was performed. The lung showed good collapse, but there was only slight temporary decrease in the cough and expectoration following each pneumothorax. After twelve weeks of this conservative treatment, the patient did not show satisfactory improvement. About five weeks previous to his operation, for no apparent reason, the clinical picture of an embolus of the brain developed. The patient was drowsy, stuporous, and at times comatose for more than a week. He had weakness of his left facial muscles and slight twitchings. He was quite disoriented. This condition cleared up entirely after ten days, and on December 20 three ribs were resected. On December 31, a cautery pneumectomy was performed and a great many small pus pockets were encountered. The postoperative course was complicated by a right-sided empyema which was drained and soon healed. The patient was discharged entirely free from all symptoms.

He has been working steadily for about two years as an engraver. He gained about 60 pounds (27.2 Kg.) in weight; the wound has remained solidly healed and he seems to be entirely well.

This case is of particular interest not only because it is a case of multiple abscesses of the lung successfully treated by cautery pneumectomy but also because there seemed to be undoubted evidence of cerebral embolism which cleared spontaneously.

CASE 3.—*Cautery Pneumectomy for Multiple Chronic Abscesses of the Lung with Bronchiectasis.*

T. G. G., a white woman, aged 23, in December, 1926, developed a cough and abundant foul expectoration which she believed were in some way connected with the extraction of a tooth in July, 1926. In March, 1927, she was operated on elsewhere for a right-sided empyema (?). Her sputum increased in amount following this operation. She was admitted to Barnes Hospital on March 26, 1927, and was operated on April 2 (fig. 3). The remaining portions of the ribs which had already been resected were removed for a distance of several inches and about 4 inches (10.16 cm.) of each of the two ribs immediately above. A small empyema cavity was found to communicate with the cavity already established and into this empyema cavity there opened three sinuses from different cavities of the lung, each of which discharged pus. Above this another large pocket which seemed to be mostly an empyema pocket was found. This large pocket contained about 50 cc. of foul smelling pus together with large masses of fibrin. The condition was therefore a multilocular abscess of the lung draining

into two different empyema cavities. The operation consisted in the removal of the roof of various cavities by the actual cautery, thus converting several small, improperly drained cavities into a single large one which could thereby be drained properly. The operation was terminated at this point.

On July 16, 1927, some remaining pus pockets in the lung were cauterized. The entire diseased area had now apparently been converted into a single large cavity. Recovery was rapid and the wound healed save for a small sinus which would not admit the tip of the finger. The patient was discharged from the hospital on August 20, and was readmitted on September 26, because the sinus had failed to close. She still had a slight cough and slight mucopurulent expectoration. On Jan. 30, 1928, a cautery was plunged into the lung along the old fistulous tract and a multilocular cavity which contained 30 cc. of foul smelling

Fig. 3.—The condition of bronchiectasis and multiple abscesses of the lung found in case 3 before cautery pneumectomy. The patient has now been completely well for a year and a half.

pus was entered. The roof of this cavity was removed with the cautery and it was tightly packed with gauze.

The postoperative course was uneventful. The patient is now shown to you, completely well. The wound is solidly healed and there are no symptoms.

Like case 2, we believe that in this case also the operation of cautery pneumectomy offered this patient the best chance of a complete recovery with at the same time the lowest risk. Simple drainage could not have been effectively carried out, collapse operations would have been likely to block whatever drainage already existed and thereby be dangerous, and ordinary lobectomy would have been both difficult and hazardous.

Unfortunately, in some cases after the operation of cautery pneumectomy a permanent bronchial fistula remains. The next case illustrates this condition. Ordinarily we do not attempt to close such a fistula until after at least two years have elapsed, because it often acts as a safety valve for residual infection of the lung.

CASE 4.—*Cautery Pneumectomy for Subacute Abscess of the Lung with Fistula.*

M. A., a white woman, aged 43, was admitted to Barnes Hospital on Aug. 30, 1922. Two months previously to admission she had her tonsils removed and following this operation developed signs and symptoms suggestive of abscess of the lung.

Physical and fluoroscopic examinations indicated a localized lesion in the right lung near the hilum. Pneumothorax treatment was attempted but was discontinued because of adhesions. A two-stage cautery pneumectomy was performed. The patient was discharged from the hospital on December 23, with a discharging sinus. Her condition improved until December 28, when she contracted a cold and cough and sputum returned. She developed severe pain in the side on which the operation had been performed.

She was readmitted to the hospital and on Jan. 18, 1923, further cauterization of the lung through the old incision was done. The patient was discharged from the hospital free from symptoms. A bronchial fistula which remained was partially closed by a plastic operation. Although she still has a bronchial fistula, she has been free from all symptoms for more than five years.

The following case illustrates not only an extensive cautery pneumectomy, but also the closure of several bronchial fistulas which remained. The result has been most gratifying. One interesting feature is that the boy was only 5 years old at the time of the cautery operation.

CASE 5.—*Cautery Pneumectomy for Chronic Abscess of the Lung and Bronchiectasis.*

D. B., a colored boy, now 11 years of age, was admitted to St. Louis Children's Hospital on Sept. 6, 1923, complaining of severe cough and copious foul expectoration. In August, 1922, he contracted a right-sided pneumonia. A thoracostomy for empyema was performed at the City Hospital in September, 1922. The cavity was drained for seven weeks and then apparently healed. In March, 1923, the patient had an attack of measles which was followed by a persistent fever. Shortly after this an abscess situated in the region of the right scapula was said to have ruptured into the lung and the patient began to be troubled with cough and foul expectoration.

On admission, physical signs combined with roentgen and fluoroscopic observations localized the lesion to the right lung. The lesion extended downward both anteriorly and posteriorly from the fourth rib.

On Sept. 8, 1923, with the patient under nitrous oxide anesthesia, a cautery pneumectomy was performed. The pleura was found to be adherent. The right lower lobe was indurated and nodular. Almost the entire lower lobe was burned out with the cautery. Six different abscess cavities were cauterized. The postoperative course was uneventful.

One month following operation the patient developed a bronchopneumonia which ran the usual course and from which he completely recovered. He was

discharged on December 23. The wound was entirely healed except for the presence of several bronchial fistulas. These were closed by an extensive plastic operation four years later. The patient is now entirely free from symptoms (fig. 4).

CASE 6.—*Cautery Pneumectomy for Chronic Abscess of the Lung and Bronchiectasis.*

E. J. H., a white man, aged 28, was first admitted to Barnes Hospital on Nov. 26, 1926, complaining of cough and mucopurulent expectoration. The onset of his illness apparently followed pneumonia at the age of 8 years. He also had another attack of right-sided pneumonia four months previous to his first admission.

Fig. 4.—External appearance of healed wound in case 5. After cautery pneumectomy, the boy had a large cavity with many bronchial fistulas. A plastic operation was performed in two stages, the wound is now solidly healed and the boy is free from symptoms. At the time of this photograph some of the scar tissue had not yet become pigmented.

From that time on his sputum was foul, occasionally blood-tinged, and he was also troubled by fever and occasional chills.

Physical examination suggested an abscess in the right lower lobe of his lung. A bronchoscopic examination performed by Dr. Arbuckle showed the right lower main bronchus to be constricted by what appeared to be a sort of web. This web was dilated and considerable pus escaped from the right lower lobe bronchus. Bronchoscopic treatment was continued at intervals. On March 7, 1927, a pneumothorax was attempted but proved unsuccessful because of pleural adhesions. Because of failure to improve under the aforementioned treatment a cautery pneumectomy was undertaken.

On March 9, 10 cm. of the seventh, eighth and ninth left ribs were resected. The lower lobe was found to be adherent, the upper lobe nonadherent. On March 16, the left lobe was entered by the actual cautery. About 250 cc. of thick foul pus was obtained. The patient was discharged after the operation much improved. Many bronchial fistulas were still present. Cough was practically negligible and the expectoration scanty.

A right phrenicectomy was performed on Feb. 6, 1929, in an attempt to diminish the size of the anatomic defect. The diameter of the wound appeared to be appreciably reduced following this procedure, although complete obliteration of the cavity will require further plastic operations. The patient is entirely free from symptoms.

BRONCHIECTASIS

We are of the opinion that all cases of chronic pulmonary suppuration are associated with some degree of bronchiectasis. In some cases the bronchiectasis is the more conspicuous part of the clinical and pathologic picture and in other cases the picture is chiefly that of chronic abscess of the lung. The next few cases which we are going to present will illustrate certain phases of bronchiectasis.

In our routine handling of cases of bronchiectasis we emphasize particularly the importance of the examination of the nasal sinuses in addition to the examination of the chest and of other parts of the body. There is no doubt in our minds that often the symptoms of bronchiectasis are made worse by chronic infection in the nasal sinuses. Conversely, it has been a frequent observation that after proper treatment of bady infected nasal sinuses the amount of purulent sputum is very greatly diminished. This result is often so gratifying that a patient's condition may be changed from an intolerable one into one of reasonable comfort merely by correcting chronic lesions of the nasal sinuses. Also it is needless to say, of course, that we feel that no examination in these cases is complete without the use of iodized oil. The method of using iodized oil, however, which we employ here is the very simple one devised by Dr. Singer which will be described separately at the close of this clinic. We also examine the sputum carefully not only for tubercle bacilli, but also for spirochetal organisms, because we think that in certain cases the use of arsphenamine and similar arsenic compounds is of some benefit. We, however, have never seen any startlingly beneficial results in bronchiectasis following the use of arsenical compounds even when the sputum contained many spirochetes. It is, of course, very necessary that the sputum be carefully examined for tubercle bacilli since bronchiectasis is a common result of chronic pulmonary tuberculosis, especially bronchiectasis in the upper lobes.

In regard to the treatment in those cases in which there are large dilated bronchi, like the fingers of a glove, in an atelectatic lobe which is the site of chronic suppurative pneumonia, we feel that no method that has yet been proposed is entirely satisfactory. After our examinations

have been completed we usually begin the treatment in such cases by comparatively simple devices. For instance, we like to put such patients on postural drainage for a few days, in order to insure them of fairly satisfactory drainage during that time and in order to relieve them of the fatigue which is sometimes incident to the repeated hard coughing which is necessary without the postural drainage. We sometimes use artificial pneumothorax when few or no adhesions are present and occasionally we have had very gratifying results. We do not feel that we can predict the presence of adhesions without introducing a needle into the pleural space. If good manometer readings are noted, air is introduced, and a therapeutic pneumothorax is maintained for several months if the collapse is satisfactory. Phrenicectomy has been of some value to us, especially if the diaphragm is mobile before the operation is performed, and particularly in cases of the lower lobe. We think that one of the explanations of the benefit from phrenicectomy is that a lower lobe may thereby be elevated and correspondingly the dilated bronchi may be brought into a more nearly horizontal position which thereby promotes better drainage. We do not think that the benefit from phrenicectomy is to be ascribed entirely to compression. The operation of phrenicectomy should not be undertaken lightly in our opinion in these cases because it sometimes interferes seriously with the expulsion of pus by coughing, and it occasionally results in the production of a severe suppurative pneumonia. Our experience with thoracoplasty in the treatment of chronic pyogenic bronchiectasis has not been so satisfactory as the reported results of others. In many cases we have used the operation of cautery pneumectomy, but we prefer to use this operation in the cases in which the predominant lesion is a chronic abscess of the lung, either single or multiple.

CASE 7.—*Bilateral Bronchiectasis and Nasal Sinusitis Treated with Pneumothorax, Tonsillectomy and Surgical Drainage of Nasal Sinuses.*

E. B., a boy, aged 11, was admitted to St. Louis Children's Hospital on March 11, 1924. In the summer of 1921, three years previous to his admission, he had an adenoidectomy. In the fall of that year he became ill with high fever and a cough which was associated with copious expectoration of mucopus. This illness lasted several weeks. From that time until admission, he had numerous similar attacks which lasted from two weeks to two months. The patient's mother said that frequently the boy coughed up as much as a pint of sputum in a day. Between attacks he would be entirely free from symptoms.

Physical, roentgen and fluoroscopic examinations, on admission, indicated a bilateral bronchiectasis, more marked on the right, although positive proof was lacking because this patient was observed before our use of iodized oil. Pneumothorax treatment of the right lung was started. The refills varied from 275 to 350 cc. of air. A good collapse was obtained. The patient was discharged on April 21, much improved both subjectively and objectively. Eight months later, the maxillary antrums were irrigated and tonsillectomy performed. Since then he has been free from symptoms.

This case illustrates a rather frequent combination of subacute nasal sinus infection with the symptoms of bronchiectasis. The sinuses in this case were treated by operation. The tonsils and adenoids were removed. The boy is now normal; he is gaining weight and is free from cough and sputum. Even in some cases of advanced bronchiectasis the amount of cough and sputum is greatly reduced after the establishment of effective drainage of chronically diseased nasal sinuses.

Occasionally, simple surgical measures produce excellent results. Phrenicectomy in addition to postural drainage is effective in a certain type of case. We have found that the elevation of the diaphragm sometimes changes the course of the bronchial tubes so that drainage by proper posture is very effective.

CASE 8.—*Unilateral Bronchiectasis Treated with Phrenicectomy and Postural Drainage.*

M. V. B., a white woman, aged 42, was admitted to Barnes Hospital on Feb. 8, 1928, complaining of cough, sputum, pain in the chest and afternoon fever. The onset of her symptoms dated back to 1925. At that time she had contracted pneumonia following a cesarean section which left her with a cough, copious expectoration and occasional hemoptysis. Rest in bed failed to clear up the condition, which was diagnosed pulmonary tuberculosis.

After admission to Barnes Hospital her sputum on repeated examinations was found negative for tubercle bacilli. Physical examination suggested a partial obstruction of the left lower lobe bronchus. A diagnostic bronchoscopy and injection of iodized oil revealed the presence of bronchiectasis of the left lower lobe. Postural drainage was started but was followed by only moderate improvement.

A left phrenicectomy was performed on February 23. The patient's symptoms became less pronounced, and gradually disappeared. She is now quite well.

This case illustrates the foregoing remarks. The patient had frequent hemorrhages, sputum and fever. She was in a tuberculosis sanatorium as a bed patient for two years without any definite improvement. Since phrenicectomy, her cough has ceased, she has gained weight and she has had no hemorrhages.

The patient in the following case was considered tuberculous for many years. Several months after the operation, he was able to do his work as a school janitor. He has had no recurrence of symptoms to this date.

CASE 9.—*Cautery Pneumectomy for Abscess of the Lung and Bronchiectasis.*

E. H., a white man, aged 40, apparently enjoyed good health until September, 1922, when he began to complain of loss of appetite and soreness all over his chest. A diagnosis of pulmonary tuberculosis was made, and he was given heliotherapy. It is to be noted that even on this occasion the patient had a productive cough and foul mucopurulent sputum. Some time later, a diagnosis of abscess of the lung was made, and he was admitted to Barnes Hospital.

The preoperative diagnosis was abscess of the left lower lobe and bronchiectasis. On July 30, 1923, 4 inches of the seventh and eighth left ribs were resected

subperiosteally. The lung was seen to glide back and forth with respiration through the unopened pleura, and for that reason the pleura was not opened but iodoform gauze was packed against it to produce adhesions. The left lower lobe felt firm and indurated. On August 6, the pleura was found to be greatly thickened. The cautery was then plunged into the indurated portion of the lung, and a cavity containing 10 cc. of thick pus was found. The roof of the abscess cavity was burned out with the cautery.

The postoperative course was uneventful. Cough and expectoration ceased after the operation and have not returned. The patient's wound healed completely.

PULMONARY TUBERCULOSIS

It has been our practice to treat all patients with unilateral pulmonary tuberculosis on the expectant plan for several months. If the patient does not improve sufficiently to warrant continuing this plan, pneumothorax treatment is instituted. This treatment is continued a sufficient length of time before phrenicectomy is resorted to followed by thoracoplasty.

We feel that patients should be in good general condition and if possible be "fever-free." Gain in weight is not sufficient evidence of good condition. A fixed mediastinum, particularly when it is drawn to the diseased side, is important. All patients should have pneumothorax if possible.

We have had some excellent recoveries after thoracoplasty but a few cases have not been benefited. We have had occasional deaths following operations from pneumonia in the opposite lung and occasionally massive collapse of the lung occurred. We are somewhat more radical in the extent of ribs removed than others. Our unsatisfactory results have occurred in cases in which we concluded that too small segments of ribs had been removed.

The following cases demonstrate the value of thoracoplasty in tuberculosis:

CASE 10.—*Unilateral Tuberculosis Treated with Phrenicectomy and Thoracoplasty.*

D. P., a man, aged 27, was admitted to Barnes Hospital on Sept. 27, 1927, with a diagnosis of pulmonary tuberculosis, referred by the Missouri State Sanatorium. The onset of his illness dated back to 1919 when he developed a dry, nonproductive cough which was shortly followed by pulmonary hemorrhage. Frequent attacks of hemoptysis had been his chief outstanding complaint. He worked at intervals until September, 1925. During this period hemoptysis was frequent. He received pneumothorax treatment from September, 1925, until September, 1927, at a tuberculosis hospital in Kansas City and at the Missouri State Sanatorium. On Oct. 13, 1927, a thoracotomy was performed and several adhesions of the upper lobe were cut. Pneumothorax treatment was then continued. The pleural effusion in the left pleural cavity which had developed after the thoracotomy gradually resorbed. The patient was discharged on December 12.

Since pneumolysis the patient has been entirely free from cough, and he also has had no hemoptysis since pneumothorax treatment was started. He was read-

mitted to the hospital on Sept. 18, 1928, complaining of weakness, heart burn and tremors. A large left-sided pneumothorax was still present. The aforementioned complaints were apparently due to the pneumothorax treatment. If, however, the patient was allowed to miss a refill he would be troubled with pains in the chest, expectoration and general malaise. On September 20, left phrenicectomy was performed. Three weeks later thoracoplasty was started and was completed in two stages with removal of portions of first to eleventh ribs, inclusive. The patient now has a feeling of well-being and is gaining in strength and weight. His appetite has returned. There is no cough or fever.

CASE 11.—*Unilateral Tuberculosis Treated with Thoracoplasty.*

A. S. W., a white woman, aged 38, was admitted to Barnes Hospital on Dec. 7, 1925, complaining of chronic cough of seven years' duration, occasional slight hemorrhage from the lung, and fever. Three of her brothers had died from pulmonary tuberculosis. During the six months previous to admission, she had lost 16 pounds (7.3 Kg.) in weight.

Physical examination showed râles over the apex of the left lung and diminished breath sounds and whispered sounds over the entire left side of the chest. The physical signs suggested a cavity in the upper lobe of the left lung. The leukocyte count was 21,650. The sputum contained many acid-fast bacilli, and the temperature varied between 37.5 and 39 C. (99.5 to 102.2 F.). The patient had two hemorrhages after her admission to the hospital.

Repeated pneumothoraces were done, from 200 to 300 cc. of air was introduced on each occasion and a good collapse of the lower lobe was obtained, but the cavity in the left upper lobe remained uncollapsed because of adhesions. A thoracoplasty in two stages was then performed. The temperature remained normal after operation, and there was an immediate reduction in the cough and expectoration. In a short time the patient was free from symptoms, and she has remained so since.

This patient had fever continuously for two years before the thoracoplasty. Almost immediately after the operation her temperature became normal, and it has remained so ever since.

CASE 12.—*Unilateral Tuberculosis Treated with Thoracoplasty.*

H. E. R., a white woman, aged 41, was admitted to Barnes Hospital on Sept. 24, 1926. She came from the Missouri State Sanatorium with a diagnosis of pulmonary tuberculosis. Her symptoms dated from the birth of her baby three years previous to her admission. Shortly after the birth of the child she developed a cough and started to lose weight. Four months after the onset of these symptoms, she developed a high fever. While at the sanatorium she regained her lost weight but her cough and elevation of temperature persisted.

On admission, physical signs, fluoroscopy and roentgenograms revealed a tuberculous process in the left lung. The right lung showed no evidence of active tuberculosis. The patient's sputum was found to contain tubercle bacilli.

On September 28, a first stage thoracoplasty was done. Two weeks later the second stage operation was performed. The postoperative course was uneventful. A good collapse was obtained. The patient was discharged on December 21, greatly improved. Her cough and expectoration were negligible.

One of the conditions in which the most gratifying results may be obtained by extrapleural thoracoplasty is tuberculous empyema, a condi-

tion which formerly was almost uniformly fatal. Some cases of tuberculous empyema, however, tax the utmost ingenuity of the surgeon. The following case is an example of such.

CASE 13.—*Chronic Tuberculous Empyema Treated with Thoracoplasty.*

R. L. P., a man, aged 21, in November, 1918, had a severe attack of influenza. Three weeks later he was operated on at another hospital for a right-sided empyema and portions of two ribs were removed. On February 28, he was taken home on a stretcher and remained in bed until May 1, 1919. The tube came out in July, 1919, but a sinus remained. In November, 1919, another rib was resected and another tube was put in. This tube remained in until the latter part of 1920. His empyema cavity was then irrigated with some antiseptic solution and apparently closed. On Feb. 1, 1921, the wound began to discharge once more and portions of three ribs were resected. The patient was again operated on in July, 1921.

He was first admitted to Barnes Hospital on April 27, 1922. His wound was still draining and tube was still in place. Operation was performed on May 10. Several sinuses were found beneath the skin and also beneath the muscles and the ribs. One of these communicated directly with a sinus high in the neck. The parietal pleura over the empyema cavity which had a capacity of 100 cc. was markedly thickened. The cavity extended upward and posteriorly and had a very narrow sinus opening into its apex. Large drain tubes containing Carrell tubes were introduced into the various sinuses to try to obliterate the empyema cavity by conservative measures before undertaking more radical procedures. On June 3, 1922, it was found that all sinuses communicated. They were laid open widely. In order to do this it was necessary to sever some of the fibers of the trapezius and rhomboid muscles, as some of the sinuses were chiefly between these muscles and the wall of the chest. The granulation tissue which was excised for microscopic examination showed miliary tubercles. On August 15, the entire cavity apparently measured only 25 cc. On Sept. 11, 1923, it was found that a ring of bone had formed around the entrance to the main drainage tract and was perhaps partly responsible for the failure of the empyema cavity to heal. It was completely removed and it was then observed that only a long sinus tract which would hold about 50 cc. remained. A flap of the pectoralis major muscle was dropped into the tract, and a little pressure with an ordinary sea sponge was made on the skin flap.

The patient was discharged much improved. His sinus discharged but little. He had gained in strength and weight. He reentered the hospital on Nov. 9, 1927, after an interval of four years, complaining of some discharge from two sinuses in the right axillary region. On November 11, a portion of newly formed bone over the two discharging sinuses was removed, and it was then found that the cavity could be completely obliterated by pressure. The patient was discharged on November 23. One small sinus still remains.

This patient had several operations elsewhere. It was found necessary to do a complete thoracoplasty and to open several sinuses before any good results were obtained. He has been working as a clerk in a railroad office for several years in spite of a small discharging sinus.

CASE 14.—*Unilateral Tuberculosis and Tuberculous Empyema Treated with Pneumolysis, Phrenicectomy and Extrapleural Thoracoplasty.*

Fig. 5.—Final result in case 14, a case of unilateral tuberculosis and tuberculous empyema.

Fig. 6.—Same patient as in figure 5 with wound solidly healed.

A woman, aged 19, was admitted to Barnes Hospital on Jan. 24, 1928. For three and one-half years previous to admission, she had chronic productive cough, slight elevation in temperature in the afternoons and loss of weight. For three years she was a patient at the state sanatorium at Mount Vernon, Mo., during which time she received pneumothorax treatment with marked improvement. The treatment was therefore discontinued and the lung allowed to reexpand. After four months she had a recurrence of all her symptoms, and pneumothorax treatment was again started.

Physical examination of the patient on her admission to Barnes Hospital revealed a tuberculous process in the right upper and middle lobes. Complete collapse by artificial pneumothorax was found to be impossible because of adhesions. On Jan. 31, 1928, with the patient under gas anesthesia, a right pneumolysis was performed and one adhesion was severed by the cautery. At the time of the pneumolysis several tubercles were found on the pleura. Following this operation, good collapse was obtained. The patient then developed clear fluid in her right pleural cavity. Repeated aspirations were necessary, and large amounts of fluid were withdrawn. Further attempts at pneumothorax proved unsuccessful. A right phrenicectomy was done on April 3. A bulging of the pneumolysis incision then developed. This was found to be a tuberculous empyema necessitatis, which was drained.

A right thoracoplasty was later done in two stages. The postoperative course was satisfactory. The patient was discharged on October 18, with the tuberculous process completely healed. All symptoms present on admission had been arrested (figs. 5 and 6).

CASE 15.—*Chronic Nontuberculous Empyema Treated with Thoracoplasty.*

J. C. S., a white man, aged 39, was first admitted to Barnes Hospital on April 5, 1920. His chief complaints on admission were those referable to a chronic left-sided empyema which had resulted from a bullet wound in 1908. The bullet had been removed but the wound continued to drain. Two years later (1910), portions of two ribs were resected to permit of freer drainage. After this procedure, the patient improved sufficiently to return to work. His wound did not heal entirely, but there was little discharge for the next two years. In 1912, the discharge became more profuse, and portions of more ribs were resected. The wound healed, except for one small sinus, and he was free from disturbing symptoms from 1912 to 1920.

Two months previous to admission to Barnes Hospital, he began to have pains in the left side of the chest and arm, which became so severe that he was unable to use his arm. On April 9, 1920, an incision was made just superior to the tunnel-like sinus. The newly formed ribs were found to be enormously thickened and fused. This large plaque of bone was removed and a shallow cavity uncovered which extended almost to the apex of the lung. A muscle flap was turned into the cavity after the lower 2 inches (5 cm.) of the scapula had been resected. The patient was discharged from the hospital on June 23, 1920. The empyema cavity and sinus had been obliterated, and the wound was entirely healed.

The patient was again admitted to Barnes Hospital on Aug. 18, 1920, for an osteomyelitis of the radius and ulna of the left arm. On Aug. 29, 1921, he was admitted for incision and drainage of a subperiosteal abscess of the left humerus, and on Jan. 19, 1927, for chronic osteomyelitis of the right tibia.

This patient's last admission was on Dec. 8, 1928, because of severe pain under the left shoulder blade. A slight discharge from the old operative wound on the right leg was still to be noted. Breath sounds over the apex of the left lung

posteriorly were diminished. The muscles over this area were tense and tender. On December 24, an incision was made over this tender area and about 200 cc. of thick, odorless pus which contained a pure culture of staphylococci was removed. No opening into the pleura could be demonstrated. The possibility of a subperiosteal abscess of osteomyelitis of a rib could not be excluded. The patient was discharged from the hospital on Jan. 19, 1929. His wound is entirely healed, and he is now free from all symptoms referable to his chest.

TUMORS OF THE PLEURA AND LUNG

Tumors of the pleura and lung represent interesting problems in chest surgery. The malignant type of tumors have been particularly

Fig. 7.—Myxoma of mediastinal pleura removed from case 16. The scale is in centimeters.

so. We feel that patients with such conditions, if seen early, might be benefited by surgical measures, but they rarely present themselves for diagnosis and treatment. One of our patients who had a small bronchial carcinoma which was removed bronchoscopically is still free from any evidence of recurrence a year later. Many others were treated by cautery, the roentgen rays and radium, but all cases ended fatally.

CASE 16.—*Myxoma of Pleura, Surgical Removal.*

F. N., a man, aged 54, was admitted to Barnes Hospital on May 25, 1923, complaining of a lump in the right breast. Physical examination revealed a spherical tumor situated in the region of the third and fourth ribs on the right side. There was no evidence of any pleural effusion or of any compression of

any of the large blood vessels. The tumor was firmly attached to the wall of the chest.

On May 28, 1923, operation was performed. The tumor was seen to be growing between the third and fourth ribs, which showed marked spreading as a result of pressure. The intercostal muscles were also thinned out. The tumor extended under the sternum, from which it could be easily separated. It apparently arose from the mediastinal pleura. A microscopic section showed typical myxomatous tissue (fig. 7).

The patient was discharged on June 9, 1923. He reported for observation on September 12, and then said that he was quite well and had been working for three months. At the present time he is perfectly well.

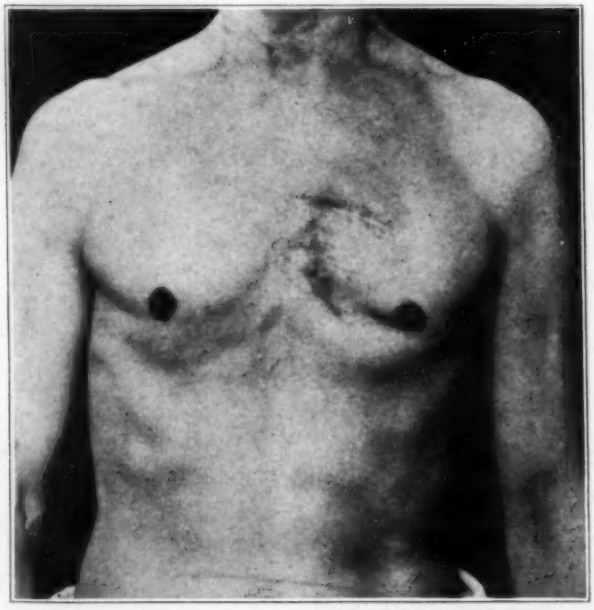

Fig. 8.—Scar in case 17 following cardiolysis for chronic mediastinal pericarditis.

CARDIOLYSIS

CASE 17.—*Cardiolysis for Chronic Mediastinal Pericarditis.*

We present this case not only because of an excellent result obtained but also because we feel that more interest in this type of case should be aroused than at present exists. The patient was referred to us by Dr. Elsworth Smith. He was admitted to the hospital in January, 1923, because of evidence of cardiac decompensation which had been present for six weeks. There had been no improvement after digitalis therapy. Atypical signs and features of chronic mediastinopericarditis were found on examination, and on May 2, 1923, with the patient under local anesthesia, the third, fourth and fifth ribs on the left side were resected from the border of the sternum to a line well out beyond the heart. This resection included both ribs and costal cartilages. Some of the sternum was also removed with a rongeur. The periosteum and perichondrium of the ribs were carefully stripped from the pleura so that there would be no regeneration

of new bone or new cartilage. The pleura was not opened. His recovery from the operation was prompt and he has been at work now for more than five years in a clerical position which requires him to work for ten hours a day. He has had no return of cardiac decompensation since the operation. This operation should be performed much more often than it is, because there are many more persons seriously handicapped by chronic mediastinal pericarditis than is commonly realized (fig. 8).

RESULTS OF CAUTERY PNEUMECTOMY IN CHRONIC PULMONARY SUPPURATION

We thought that it would be of interest to report to the organization at this time the results of the cases of chronic pulmonary suppuration treated by the operation of cautery pneumectomy. It should be understood that this operation is reserved for only the most refractory cases. We find, moreover, that it is of greater value and probably less dangerous in those cases in which the predominating features of the picture

Data on Cases of Chronic Pulmonary Suppuration Treated with Cautery Pneumectomy

Number of cases	54		
Definitely improved	36	(66.6%)	
Moderately improved	2	(3.6%)	
Slightly improved	3	(5.6%)	
Not improved	7	(12.6%)	
Dead (operative mortality)	6	(11%)	
Late Results			
Number of cases	54		
Number of patients still alive	36	(66.6%)	All patients at work
Definitely improved	34	(63%)	
Moderately improved	1	(1.6%)	
Slightly improved	0		
Not improved	1	(1.6%)	
Operative deaths	6	(11%)	
Late deaths, not directly due to operation	12	(22%)	
Bronchial fistula still present	17	(47%)	

are of chronic abscess of the lung rather than of cylindric bronchiectasis. The statistics in the accompanying table do not include cases accompanied by carcinoma of the lung.

In the table we have divided the deaths into those which were directly ascribable to the operation and those which occurred late and were due to causes not directly ascribable to the operation. It is, of course, somewhat difficult to state with certainty that some of these late deaths were not caused by the operation, but since they include deaths which occurred at variable times from two months to two years after the operation of cautery pneumectomy, it was felt that they should not be ascribed to the operation itself.

Of the twelve cases in which death occurred late after the operation, one was due to an acute enteritis which seemed to be entirely independent of either the operation or the original suppurative pulmonary condition. Another one was reported to us as a sudden death at home, the cause of which could not be ascertained. A third was due to pulmonary tuberculosis in a case in which the patient's original condition was a tubercu-

lous abscess which had been treated by cautery pneumectomy. A fourth patient died from bronchopneumonia which may have been due to residual infection in the lung. Two patients died more than a year later from brain complications; in one case an abscess of the brain and in the other meningitis. In these last two cases, the fatal lesions were due undoubtedly to the fact that some of the original infection in the lung still remained. In two patients, a generalized infection of the blood stream was present; in one instance it was associated with diabetes. It is probable the operation on these two patients should not have been undertaken. Two other patients died more than a year after the cautery pneumectomy as a result of operations to close the bronchial fistulas. In one of these cases death occurred suddenly, presumably due to air embolism, and in the other one the patient died as a result of a generalized infection presumably due to contamination of the wound by the pus from the bronchial fistulas. In both of these cases the patients were free from symptoms and died merely because they desired to have the bronchial fistulas closed. In two other cases death occurred from hemorrhage from bronchial fistulas. Both of these deaths occurred several months after the operation of cautery pneumectomy.

3. BRONCHOGRAPHY *

JACOB J. SINGER, M.D.
ST. LOUIS

We who work in the chest service of Barnes Hospital agree with others who regard bronchography as a method which has revolutionized the diagnosis of pulmonary conditions. Since the introduction of iodized oil 40 per cent, as suggested by Sicard and Forestier, we have been able to perform lung mapping without any danger to the patient and with most gratifying results in diagnosis.

There are seven methods of introducing iodized oil:

(1) Through a trocar needle, resembling a tracheotomy tube, into the trachea, under sterile precautions.

(2) Under direct laryngoscopic examination with the patient lying on the back, with the head extended over the table.

(3) Through the bronchoscope introduced directly into the lung.

(4) Through a tracheal catheter introduced under indirect illumination of the larynx.

(5) Through the passage of a specially constructed intubation tube.

(6) Passive method of aspiration. After complete anesthesia of tonsillar pillars and trachea, the patient is given the oil by mouth and instructed to aspirate it.

(7) By the injection into the pharynx of 20 cc. of oil while the patient pulls out his tongue as far as possible. The patient should be trained to take many successive deep breaths following the injection of the oil. This method which we proposed in 1925 is the one which we most commonly use.

The iodized oils used were lipiodol (Lafay), which contains 40 per cent of iodine by weight combined with poppy seed oil; and iodipin, which contains 40 per cent by weight combined with sesame oil. Iodipin can be obtained in either 10 or 40 per cent compounds. It is possible that other oils can be used, but the two mentioned are the ones we use in our work.

In these two products the iodine is so firmly combined with the oil that the iodine reaction cannot be obtained in patients who are expectorating sputum combined with the oil. Iodized oil is not rapidly broken down in the lungs but may be in the gastro-intestinal tract, when it is swallowed or when through accident the oil is introduced into the esophagus. Iodism may thus result.

The choice of the seven methods of technic in use usually varies with the experience of those interested in the methods. Laryngologists prefer the bronchoscope; pediatricians, the tracheal trocar. Medical men and

* From the Department of Internal Medicine Washington University School of Medicine and Barnes Hospital.

Fig. 1.—Method of introducing the iodized oil. The patient faces a good light and is told to open his mouth as widely as possible; his tongue is grasped with a piece of gauze and is pulled out as far as possible. Iodized oil which has previously been warmed in a syringe is slowly injected into the posterior pharynx through a straight cannula while the patient breathes deeply. The patient is urged not to swallow or cough during the injection. The use of a local anesthetic is seldom necessary.

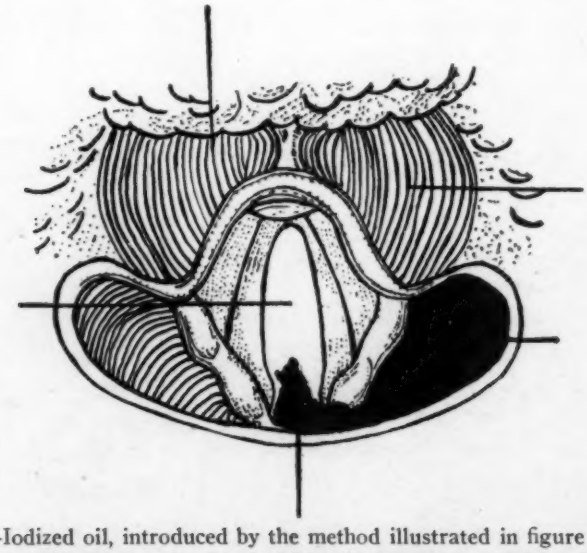

Fig. 2.—Iodized oil, introduced by the method illustrated in figure 1, collects in the interarytenoid fossae. It then trickles between the vocal cords during the phases of respiration and is thus aspirated into the bronchial tree.

roentgenologists prefer the intratracheal injection through the mouth. Irrespective of the method used, approximately from 20 to 40 cc. of the oil must be instilled to produce suitable roentgenograms.

The value of bronchography lies in the definite mapping out of lung structure, either normal or altered by pathologic conditions. It requires considerable experience to be able to interpret these shadows, especially with so dense or so opaque a substance. In view of the fact that the lung fields may extend in an anterior and a posterior direction from 6 to 12 inches (15.2 to 30.4 cm.), one can readily understand how superimposing shadows will complicate the roentgenogram, but the true interpretation will be made in conjunction with the physical signs and history. Many dense shadows in the roentgenogram may be tumor masses, collapsed lung tissue or cavities filled with secretion. The opacity of the iodized oil when introduced into the lungs of these patients will often give startling pictures of pathologic conditions that were not suspected.

The oil can be used in fistulous tracts to map out chronic empyema cavities and also bronchial fistulas, and when introduced in this way it rarely excites a cough. This substance has helped to show abscessed cavities that were connected with the empyema cavities through a bronchial fistula.

In pneumothorax cases, and especially in bronchiectatic cases, iodized oil shows well whether or not the bronchi are collapsed.

Jacobaeus, in a recent article, described how the iodized oil in pneumothorax cases has shown that bronchial tubes were seen in adhesions extending to the wall of the chest. One can easily see how it could be possible to sever lung tissue with the cautery in Jacobaeus' method of pneumolysis and produce an empyema and probably death.

To summarize the value of bronchography, it is of great benefit, in combination with careful physical examination, to those who have had considerable experience with suppurative conditions of the lung. It should not be used when simpler methods suffice for the diagnosis. It shows excellently the bronchial tree with abnormalities present, and when properly used it is harmless.

The first method is recommended for children, the fourth and seventh methods for adults, and the second and third methods when bronchoscopy is performed for other purposes. The seventh method should be tried in adults before attempting the more complicated ones. If successful, then the fourth is the method of choice.

Recently, Iglauer devised an intubation tube which prevents regurgitation of the oil. While this method has much to commend it, one should use means with as little instrumentation as possible to obtain the desired roentgenogram.

DEMONSTRATIONS OF EXPERIMENTAL WORK IN THE WASHINGTON UNIVERSITY SCHOOL OF MEDICINE

1. CALIBER CHANGES IN THE BRONCHI IN NORMAL RESPIRATION *

PETER HEINBECKER, M.D.
ST. LOUIS

The use of iodized oil 40 per cent has permitted the outlining of the bronchial tree in the living subject with great accuracy and detail. This suggested it as a possible agent in determining the caliber changes believed to occur in the bronchi in normal respiration.

EXPERIMENTS

Observations were carried out on living subjects—one cat, two dogs and five human beings. The animals were anesthetized with ethyl carbamate (urethane), and the oil was administered by tracheal puncture. In man, where no anesthetic was required, the films were taken in the course of diagnostic procedures. After injection of the oil, x-ray films were taken during the actual process of breathing, and in man also while holding the breath at the end of inspiration and at the end of expiration. The respiratory movements were recorded by a pneumograph held around the chest by a tape and attached to a tambour. The moment of the time of exposure of the film was signalled on the record. To record accurately the time of exposure with reference to the particular phase of respiration it is well to have the kymographic marking key and the x-ray circuit operated by the same switch, but it was not possible to arrange this in these experiments. All roentgenograms were taken at a constant distance, 3 feet (91.44 cm.), and the exposures made short to avoid motion in the pictures.

Results showed that the bronchi and bronchioles are widest at the end of full inspiration and narrowest at the end of full expiration. In quiet breathing the changes in caliber are slight. In some of the long bronchi, particularly in those to the lower lobe, there is an actual narrowing during the first part of inspiration. While these observations were puzzling at first, it was seen that they could be explained on the

* From the Department of Surgery, Washington University School of Medicine and Barnes Hospital.

* This report is in part an abstract of data presented in a paper, "A Method for the Demonstration of Calibre Changes in the Bronchi in Normal Respiration," published in *The Journal of Clinical Investigation* (**4**:459 [Oct.] 1927).

basis of passive changes. The roentgenograms showed that the bronchi, especially the ones to the lower lobe, lengthened considerably during respiration. Passive mechanical changes in caliber would therefore be the resultant of linear and radial traction. The linear changes would be greatest at the beginning of inspiration, at the time of the descent of the diaphragm, especially in respect to the lower lobes. Radial traction would be greatest at the end of inspiration on elevation of the ribs, when the anteroposterior and lateral diameters of the lungs are at a maximum. During quiet respiratory movements the tendency to widen during inspiration due to radial traction might almost be equaled throughout the greater portion of the lungs by the tendency to narrow due to linear traction.

To study the passive changes which might occur in the bronchi during inflation and deflation of the lungs, experiments were performed on two cats after death. The recently killed animal was placed in a large rigid cardboard paper cylinder so fitted that exhaustion of the air within the cylinder by a water suction pump was possible. A tracheal cannula, firmly tied in, opened to the atmosphere through a rubber stopper in the lid of the cylinder. The iodized oil was administered through the cannula. Roentgenograms were taken with the cat's lungs inflated and deflated by negative pressure to varying degrees. A waxed paper cylinder was used because it interfered with the passage of the x-rays less than glass.

The results proved that the longitudinal and radial changes demonstrated in the roentgenograms of the living lung could be paralleled in the dead lung when they were entirely passive. The sequence of passive changes was a shortening and narrowing of the bronchi with deflation; an elongation and possible narrowing with partial inflation and a widening with more extensive inflation.

The presence or absence of active influences in the respiration of the living subject was not determinable from the evidence of this investigation. Numerous researches have shown that the caliber of the bronchi is under nervous control. Even if there is no active participation on the part of the bronchial musculature in ordinary respiration, it would still exert its influence as an elastic structure the degree of stretching of which would vary with the degree of vagus and sympathetic tone.

Information having a bearing on the study of the nervous mechanism of the bronchi has been secured through an analysis of the action potential of the sympathetic and vagus nerves of the turtle. It has been found [1] that the action potential of the cervical sympathetic trunk

1. Heinbecker, Peter; and Bishop, George H.: Proc. Soc. Exper. Biol. & Med. **26**:645, 1929.

is in general composed of two wave complexes, but that in certain of such nerves there are three. For the purposes of identification, these are named the *A*, *B* and *C* groups. When present, the *A* group has a threshold, a conduction rate and an absolutely refractory period time similar to the alpha, beta, gamma and delta groups of the frog sciatic as described by Erlanger and Gasser. The *B* and *C* groups have a threshold, conduction rate, chronaxia and absolutely refractory period time which differentiates them entirely from the *A* group. The threshold is higher, the conduction rate is less and the chronaxia and absolutely refractory time are approximately from five to ten times that of the *A* group. Microscopic sections indicate that the *A* group potential, when present, arises from the largest relatively thinly myelinated fibers in these nerves. The *C* group arises essentially from the unmyelinated fibers and the *B* group essentially from the small thinly myelinated fibers always associated closely with the unmyelinated nerve fibers.

The vagus nerve has an action potential similar in form to that of the sympathetic with the *A*, *B* and *C* potential groups. The properties of the potential groups are also the same as those of the sympathetic nerve.

The analysis of the form and properties of the action potentials of these nerves affords a basis for further work in the identification of the fiber groups in similar nerves responsible for functional changes occurring in the musculature of the bronchi in animals.

2. CHANGES IN THE SHAPE AND SIZE OF THE TRACHEOBRONCHIAL TREE FOLLOWING STIMULATION OF THE VAGO-SYMPATHETIC NERVE *

BYRON F. FRANCIS, M.D.
ST. LOUIS

Changes in the caliber of the bronchi in response to vagus stimulation have been observed by many. As long ago as 1842, Langet [1] directly observed constriction of the bronchi of the horse when the peripheral end of a cut vagus nerve was stimulated. Dixon and Brodie,[2] in 1903 and 1904, studied the effects of nerve stimulation by recording changes in intratracheal pressure and changes in the volume of a lobe of the lung which had been placed in an oncometer. The method was modified somewhat and used by Weber [3] in 1914, and by Braeucker [4] in 1925 and 1927, in making further studies. The results of the investigations of these and many others have been overwhelming proof that the caliber of the bronchi may be changed by impulses traveling through the vagus nerve. An admirable review of the entire subject has been presented by Macklin in a recent issue of the *Physiological Reviews*.[5]

However, a study of the changes in size and shape of the bronchi which take place within the intact chest as a result of nerve stimulation, and of how the respiratory movements might modify these changes has not been made. It is my purpose to record a study of these changes. The method used is similar to the one employed by Heinbecker [6] in demonstrating changes in the size of the bronchi during normal respira-

* From the Chest Service of Barnes Hospital and the Department of Medicine, Washington University School of Medicine.

1. Langet: Recherches expérimentales sur la nature des movements intrinséques du poumon et sur une nouvelle cause d'emphysème pulmonaire, Compt. rend. Acad. d. sc. **15**:500, 1842.

2. Dixon, W. E., and Brodie, F. G.: The Bronchial Muscles, Their Innervation and the Action of Drugs upon Them, J. Physiol. **29**:97, 1903.

3. Weber, E.: Ueber Experimentelles Asthma und die Innervation der Bronchialmuskeln, Arch. f. Physiol. **142**:63 1914.

4. Braeucker, W.: Die Experimentelle Erzeugung des Bronchialasthmas und seine operative Beseitigung, Arch. f. klin. Chir. **139**:1, 1925; ibid. **137**:463, 1925. Braeucker, W., and Kummell, H.: Ueber die "reine" Vaguswirkung an den Bronchien, Pflüger's Arch. f. Physiol. **218**:301, 1927.

5. Macklin, Charles Clifford: The Musculature of the Bronchi and Lungs, Physiol. Rev. **9**:1 (Jan.) 1929.

6. Heinbecker, Peter: Method for Demonstration of Calibre Changes in Bronchi During Respiration, J. Clin. Investigation **4**:450 (Oct.) 1927.

tion. It is essentially the recording roentgenologically of the tracheobronchial tree after injections of a substance opaque to the roentgen ray have been made. By this means changes in the outline of the trachea and bronchi may be noted by comparison of the films that have been taken during various steps in the experiment.

EXPERIMENTS

Dogs and cats were used. The animals were anesthetized by sodium barbital injected intraperitoneally. Dry bismuth subcarbonate powder was blown into the tracheobronchial tree. This was found to be more satisfactory than iodized oil, because it coated the walls better and tended to remain as it was originally distributed, whereas the iodized oil soon flowed out of the upper bronchi into the

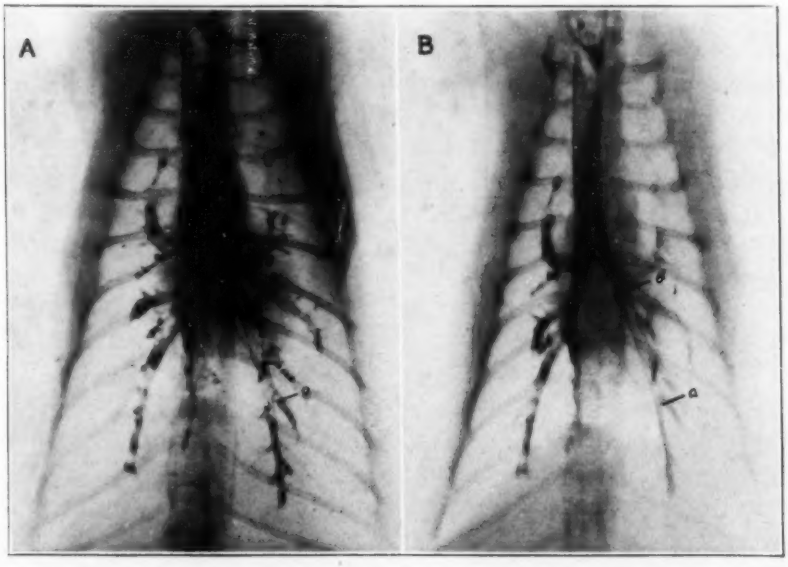

Fig. 1 (cat).—Both vagosympathetic nerves were cut to slow and deepen respirations. *A* was taken at height of inspiration; *B*, at end of expiration. The small letters *a* and *b* in this and in figure 4 indicate comparable regions of the tracheobronchial tree.

lower bronchi or into the alveoli, drowning portions of the lung. The vagosympathetic nerve was isolated in the neck, and stimulation was effected by a faradic current.

X-ray plates of the chest of the animal were taken with the tube at a constant distance from the plate; in this series the distance was 26 inches (65.96 cm.). To determine the time and duration of the exposure in relation to the respiratory cycle, records of the respirations and exposure were made simultaneously on a kymographion. Closing of the switch of the x-ray machine also closed the key of the marker on the drum. A record was similarly made of the time and duration of the stimulation of the nerve.

In figure 1, *A* was taken in inspiration. That this is so is noted by the increase in the width of the chest and the depth of the diaphragm. It

is easily seen that the entire bronchial tree, including the trachea as well as the bronchi, is longer and wider. Actual measurements of a portion of the left bronchus between the two marks are: on inspiration an average width is 3.75 mm., the length, 37 mm. For the purpose of comparison, if I may be permitted to compute the probable capacity of the tubes from these data, it is seen that the capacity of this section of tube is about 1,634 c.mm. In expiration, the length of this tube has become 33 and the width 3 mm., giving a capacity of about 933 c.mm.

The capacity in inspiration is therefore 1.75 times that in expiration. If this is an indication of the extent of changes throughout the bronchial tree, as it seems to be, the dead space of the lungs is far from a fixed quantity. This fact has been pointed out many times before. Changes in the size of the bronchi during the respiratory cycle were surmised by Keith [7] and demonstrated by Macklin [8] and Heinbecker.[6] Ballon and Ballon [9] have shown changes in the size of the bronchi which had been filled with iodized oil by making an exposure during inspiration and during expiration on the same plate.

In figure 2, it is to be noted that the size of the chest is the same in *A* and *B*. By actual measurement on the film the chest in B is 2 mm. narrower than that in *A* at a level which is just below the bifurcation of the trachea, but otherwise there is no change. It will be noted, however, that there is a general narrowing of about 1 mm. of the right bronchus. The trachea is narrower also. The left bronchus is slightly narrower. That the two plates were taken in the same phase of respiration is further shown by the record. In figure 3, it is seen that the control plate, figure 2 *A*, was made just at the beginning of inspiration (2). Figure 2 *B* was taken at 5, which is at about the same point in the respiratory cycle as 2, and about eleven seconds after stimulation of the peripheral end of the cut right vagosympathetic nerve began. The beginning of stimulation is indicated at 4. More marked changes in size and shape of the bronchi are shown by stimulation of the uncut vagus nerves.

The most marked changes in size and shape of the tracheobronchial tree occurred when the intact vagi were stimulated. By comparing figure 4 *A* with figure 4 *B*, a marked difference is seen.

In figure 4, both exposures were made with the animal in an oblique position. The chest of the animal is narrower in *A* than in *B*, but the

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7. Keith, A., in Hill, L.: The Mechanism of Respiration in Man in Further Advances in Physiology, London, E. Arnold, 1909.

8. Macklin, C. C.: X-Ray Studies on Bronchial Movements, Am. J. Anat. **35**:303, 1925.

9. Ballon, D. H., and Ballon, H. C.: Pneumonography with Iodized Oil, 40 Per Cent, by Bronchoscopic Method: The Bronchial Tree, with Observations Made from One Hundred Injections, Arch. Surg. **14**:184 (Jan.) 1927.

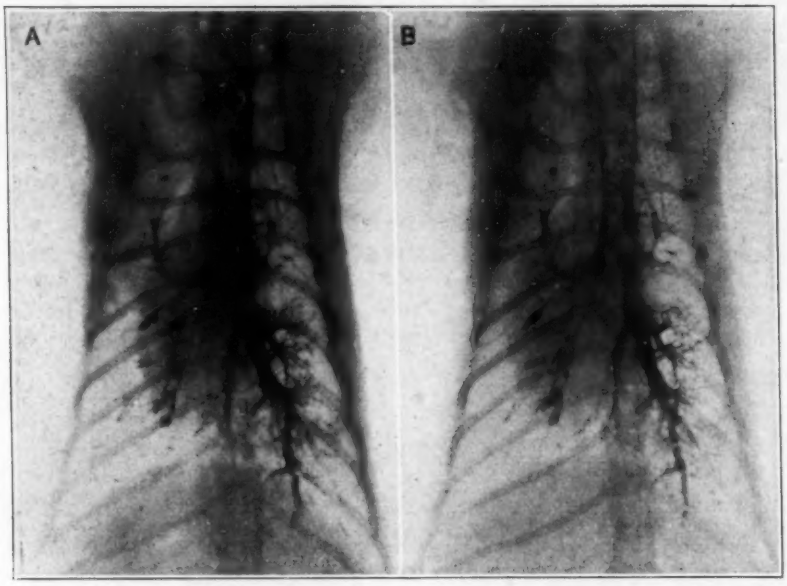

Fig. 2 (cat).—Both vagi were cut. *A* was taken before stimulation; *B*, during stimulation of the peripheral end of the right cut vagus. Both exposures were made at the same phase of the respiratory cycle. See figure 3.

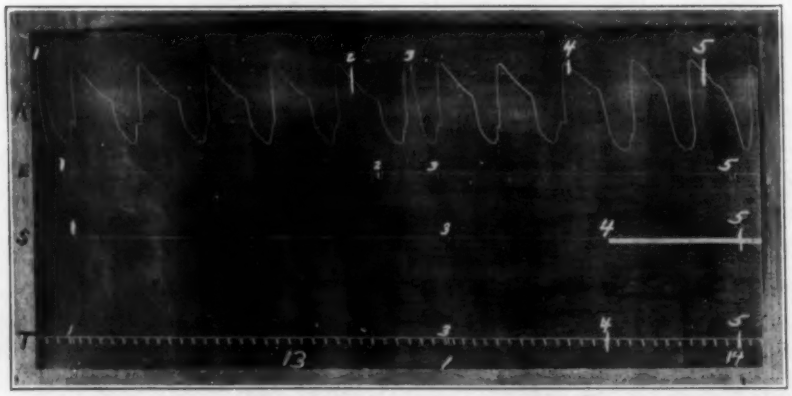

Fig. 3.—Simultaneous record of respirations, time of exposure, time and duration of stimulation made. *R* indicates the respiratory tracing, upstroke is expiration, downstroke is inspiration; *E*, exposure; *S*, stimulation; *T*, time in seconds. Figure 2 *A* was taken at 2; and figure 2 *B* at 5.

diaphragm is at the same level in each. Measurements of the left bronchus give some significant results. Between the two marks the distance is 30 mm. in each but the diameter in *A* is 1.75 and in *B* it is 4 mm. A calculation of the capacity gives 72.159 for *A* and 376.99 c.mm. for *B*, a change of more than five times. Only a slight edema of the mucous membrane of a bronchus so constricted would completely occlude its lumen. The localized constriction of the right bronchus with the dilated region beyond the narrow portion gives one the impression of a peristaltic-like wave in process.

It does not seem likely that this change in the bronchi is a passive one due entirely to changes in capacity of the chest from a disturbance

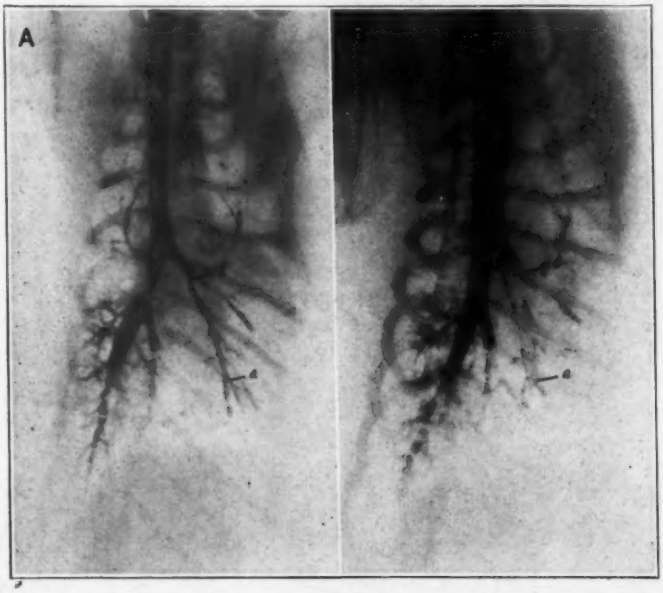

Fig. 4 (cat).—Oblique position; *A* was taken during stimulation of both uncut vagosympathetic nerves in the neck; *B*, two minutes after cessation of stimulation.

of the respiratory movements caused by stimulation of the uncut vagus. If this were so, one would have expected a great diminution in the size of the left side of the thorax. This did not occur. So far as can be determined from a study of the film, a change in the capacity of the chest comparable to the change which took place in the bronchi did not occur. For this to have happened the chest must have had its diameter reduced to one-half; this would have reduced the capacity about four times. As it was, from the measurements made of the x-ray plate, the capacity could not have been reduced more than one-third. In this case, the trachea alone had its capacity reduced more than three times as the result of the change in size.

In the cat in figure 5 *A*, the cervical portion of the left uncut vagosympathetic nerve was stimulated. *C* was taken during a stronger stimulus than that given while *B* was taken. It is to be noted that the thorax is longer and narrower in *C* than in *B*, but the trachea in *B* is nearly 1 mm. narrower than that in *C*. In each the bronchi have been extremely narrowed, out of proportion to the change in width of the chest when compared to *A*, which was taken after stimulation had ceased.

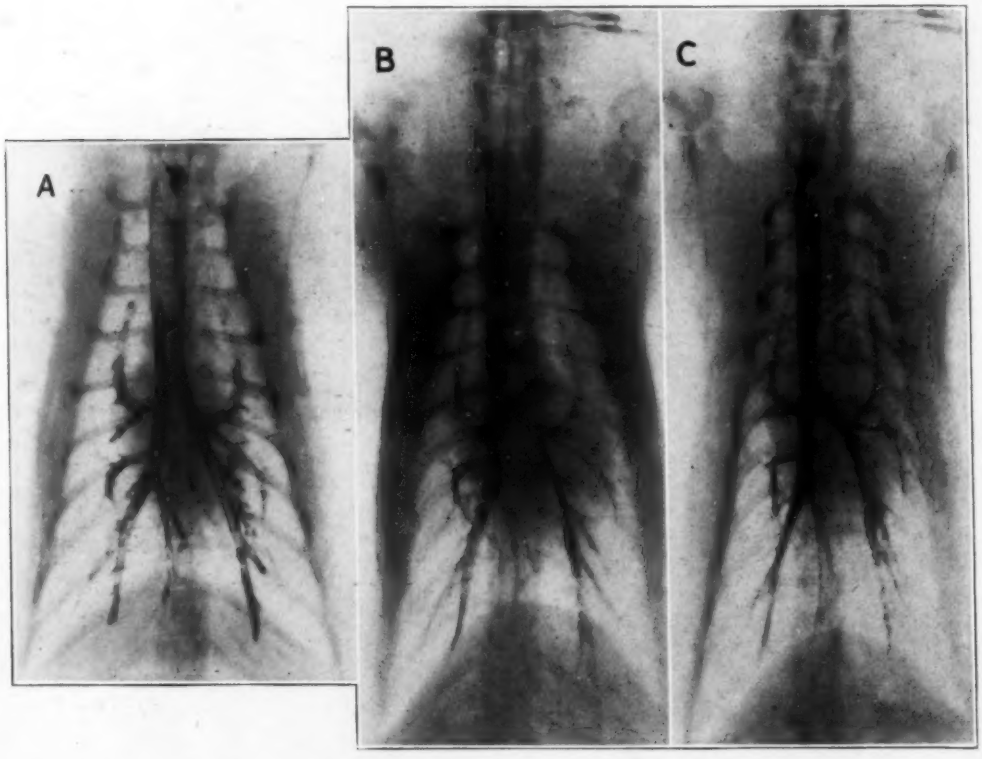

Fig. 5 (cat).—Anteroposterior position; *A* was taken at the end of a normal expiration, *C* during strong stimulation of the left uncut vagosympathetic nerve, and *B* during mild stimulation of the same nerve.

Cats lend themselves to this type of experimentation better than dogs, chiefly because the anteroposterior diameter of the chest of a cat is relatively short so that x-ray pictures may be taken with the animal lying on its back. Dogs, on the other hand, have a narrow chest but an anteroposterior diameter which is relatively great. Consequently it was usually necessary to take lateral plates.

Figure 6, taken of dog *J*, shows changes in the tracheobronchial tree. *A* was taken before stimulation. The right side of the chest was toward the plate; the trachea and right bronchus filled with bismuth subcarbonate are seen. *B* was taken five seconds after the beginning of stimulation of the right uncut vagosympathetic nerve. A marked general narrowing of the trachea and right bronchus is apparent. Both pictures were taken in expiration. By measurements of the two plates one cannot detect any difference in the size of the thorax.

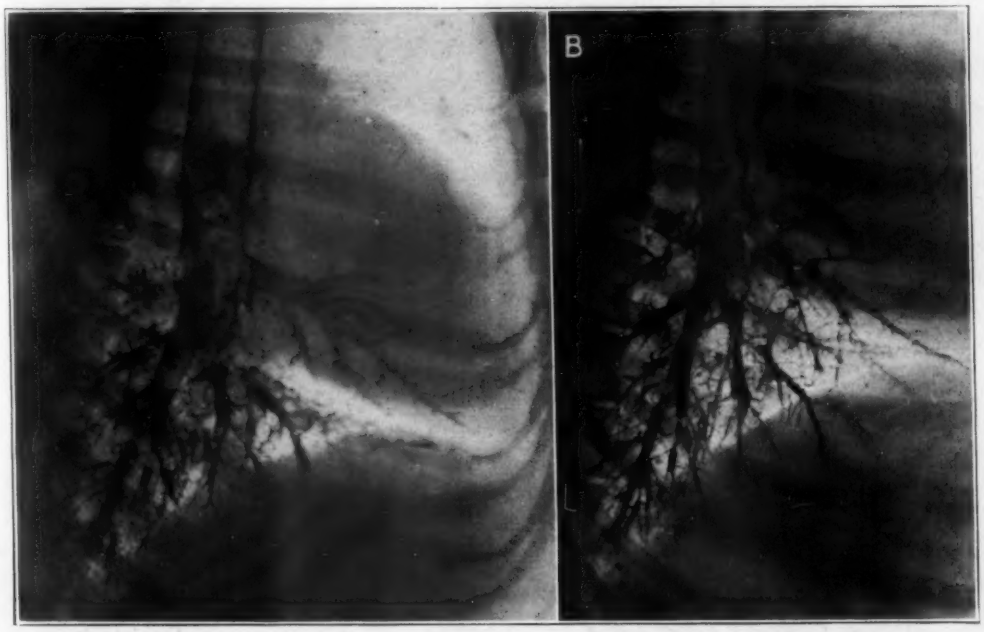

Fig. 6 (dog).—Right side to the plate; *A* was taken before stimulation; *B*, five seconds after beginning of stimulation of the right uncut vagosympathetic nerve.

COMMENT

A roentgenologic demonstration is given of the changes in the size and shape of the tracheobronchial tree of cats and dogs which occur during inspiration and expiration. Also the changes which follow the stimulation of the cervical portion of the vagosympathetic nerve are demonstrated. The evidence here presented is not thought to be sufficient to make conclusions concerning the physiology of the tracheobronchial system. However, the method should lend itself well to further investigations of the bronchi of the intact animal.

3. EMPHYSEMA SIMULATING CARDIAC DECOMPENSATION *

W. B. KOUNTZ, M.D.
AND
H. L. ALEXANDER, M.D.
ST. LOUIS

It has long been held that chronic emphysema sooner or later leads to cardiac failure. This statement appears in many modern textbooks of medicine. It is based largely on the presumption that as the lungs distend during the progression of emphysema, the pulmonary capillaries become stretched and narrowed. Consequently, the blood leaving the right ventricle meets peripheral obstruction, and added work is thrown on the right side of the heart which eventually hypertrophies, dilates and fails. This theory is founded on the clinical fact that patients with advanced emphysema usually have dyspnea on exertion, cyanosis and dependent edema, which are cardinal signs of cardiac decompensation.

In a previous study, fifty patients with long-standing bronchial asthma were examined. All of these had emphysema which, in some, was advanced. Particular attention was paid to the cardiovascular system, and little evidence of inherent cardiac damage was obtained. This led to the present study of the heart in chronic emphysema.

Sixty-six patients with emphysema were examined in detail. They were selected from moderately advanced to advanced cases. In almost all, the underlying etiology was some form of bronchial obstruction, such as asthma, chronic bronchitis or laryngeal compression. Again, particular attention was paid to the cardiovascular system. The only outstanding observations were a high peripheral venous pressure, and a lowered oxygen content of the arterial blood.

All these patients showed dyspnea on exertion and cyanosis. Dependent edema occurred in eighteen, and a history of this sign was obtained in fifteen others. These cases simulated cardiac decompensation. Nine patients with edema came to autopsy. In one there was hypertrophy of both the right and left ventricles. In eight no pathologic changes were found. In these, not only was there no right ventricular hypertrophy by measurement, but the normal ratio of right ventricular weight to left ventricular weight was maintained in each instance.

The finding of these normal hearts required an explanation of the signs of cardiac failure. Dyspnea and cyanosis may readily be attributed

* From the Department of Medicine, Washington University and Barnes Hospital.

to the low vital capacity of the lungs and the impaired pulmonary ventilation that occur in emphysema. The edema is ascribed to the high peripheral venous pressure, and anoxemia, for the two factors most conducive to edema are increased capillary pressure and anoxemia, both of which occurred in these cases.

The reason for the high venous pressure was studied in dogs. A ball valve was fastened in the trachea and adjusted so that the amount of expiratory obstruction could be regulated. Within a short time, emphysema appeared; this was permitted to continue over a period of weeks. Intrathoracic and peripheral venous pressures were recorded periodically. Increased pressure in the thorax occurred early. As this advanced, the peripheral venous pressure rose proportionately. This is accounted for by the partial obstruction to the return of peripheral venous blood into the thorax, which results from increased intrathoracic pressure.

CONCLUSIONS

From this study, the following inferences are made:

1. Heart failure is not necessarily a consequence of emphysema.

2. In cases of marked emphysema, peripheral signs simulating cardiac failure are attributed to factors other than a damaged heart.

3. These factors are lowered vital capacity (dyspnea), deficient pulmonary ventilation (cyanosis) and an increased peripheral venous pressure associated with anoxemia (edema).

4. Heart failure and emphysema may coexist, as in senile arteriosclerosis. Here, emphysema is usually not advanced, and there is no evidence that it damages the heart.

4. EXPERIMENTAL ABSCESS OF THE LUNG FOLLOWING LIGATION OF THE PULMONARY ARTERY AND INCISION AND SUTURE OF THE PULMONARY PARENCHYMA*

I. Y. OLCH, M.D.
AND
HARRY C. BALLON, M.D.
ST. LOUIS

We hesitate to add further to the literature which concerns itself with the theory concerning the development of abscess of the lung. In attempting to attack this problem from various angles, many investigators have often disregarded striking clinical observations and facts; this is an endeavor to discover a method which when perfected would carry with it a guarantee of producing an abscess of the lung in practically every instance. By so doing they have endeavored to prove that certain postoperative complications, as for example, abscess of the lung, always result from a single mechanism. Others have gone further and have concluded that a given mechanism always operates and is common to other postoperative pulmonary sequelae. Such mechanically perfect experiments naturally add considerable weight to the explanation of how such conditions develop and point out how in many instances their occurrence may best be avoided. Such a simplification, although most desirable, is certainly not justifiable at the present time. We believe that abscess of the lung may develop in several ways. We wish to stand in the middle of the road.

The object of this paper is, therefore, not to introduce a new method, to formulate further burdensome theory or to draw any sweeping conclusions from the results which we have obtained. The purpose is rather to record observations as they occurred in the hope that our experiences may at some future time add to, or help to discard a link from, the chain of theory.

Our original studies were undertaken to observe the origin of the scar tissue in healing of the lung. They were stimulated more particularly in the light of the recent experiences of others who have questioned the previously accepted conception of the development and structure of the lung. We observed that simple incision and suture of the pulmonary parenchyma resulted in a scar which resembled a scar elsewhere on the body. Phrenicotomy performed on the corresponding side in no way affected the end result. These studies will be reported elsewhere.

* From the Department of Surgery, Washington University and Barnes Hospital.

In the course of our investigations we found that ligation of the pulmonary artery and simple incision and suture of the pulmonary parenchyma were followed by the development of an abscess of the lung in the lobe so treated. We were frequently able to repeat this observation, as our recorded experiments will show. Explanation of much in this connection, nevertheless, still remains to be made. Among other things, our bacteriologic studies to date are as yet incomplete.

All experiments were performed on dogs under absolutely sterile conditions. The positive pressure apparatus of Erlanger-Gessel was employed.

Fig. 1 (dog 117).—Abscess of the right lower lobe of the lung.

EXPERIMENTAL WORK

Dog 117 (2).—The pulmonary artery to the right lower lobe was ligated. A transverse incision, which included a large main bronchus, was made in the right lower lobe. The cut ends of the bronchus were allowed to retract and the lung was resutured. The dog was killed on the seventh day. An abscess of the right lower lobe of the lung was found (figs. 1, 2 and 3).

Necropsy.—The lung was quite firm. The suture line was intact. On cutting through the lobe on which operation had been performed, a definite abscess, 2 cm. in diameter, was observed. Through this abscess ran the remains of a large bronchus which was plugged. The main bronchus just adjacent to the abscess was patent. The abscess, which was solitary, extended well out to the periphery of the lung. The pleura was free. No other abscess formation could be made out in any other part of the lung.

Microscopic Examination.—The microscopic picture verified the gross observations. The lung tissue adjacent to the abscess is filled with a fluid exudate plus inflammatory cells and red blood cells. The wall of the abscess is made of fibrin, pus cells and cellular débris. All the parenchyma of the lung in this region is destroyed. The extent of the abscess corresponds more to the extent of the incision.

Comment.—The extent of the lesion and the tremendous inflammatory reaction were strong points against a purely ischemic origin of the

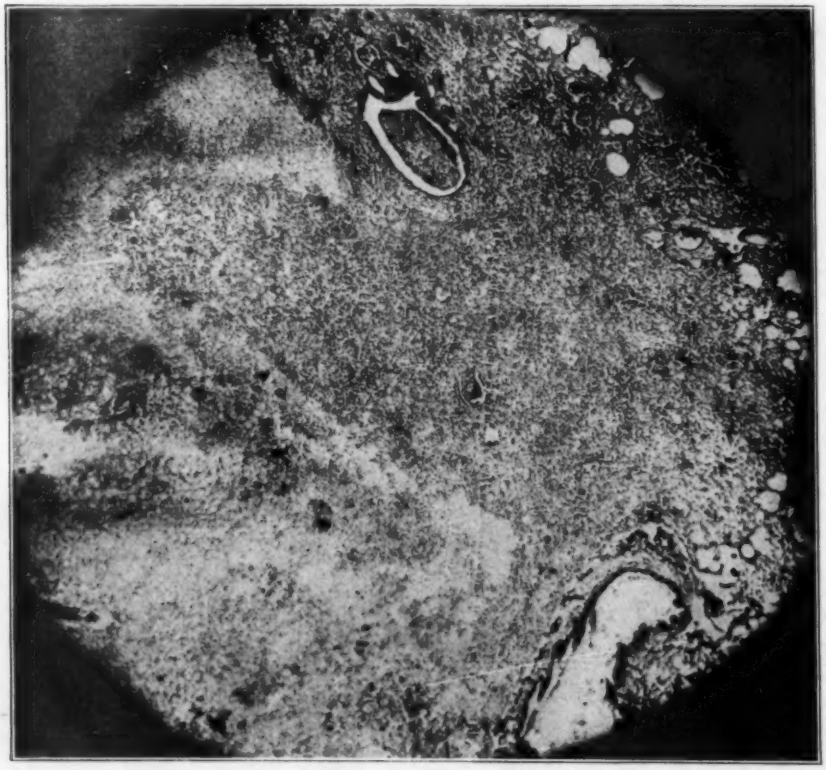

Fig. 2.—Low power magnification. Photomicrograph of abscess noted in fig 1.

lesion. All adjacent vessels contained blood. No large groups of bacteria could be discerned. The rest of the lung requires no description.

Dog B 16 (3).—The technic used was that of the foregoing experiment. For one week after the operation, this dog was quite ill. During this period it coughed, pus poured out of its nostrils, and it frequently sneezed. The condition was obviously not one of mere distemper, and the dog gradually improved. It was killed after one month. The wound was healed. Beneath it there was breaking-down of tissue, that is, an abscess.

Microscopic Examination.—Sections taken from the right lower lobe revealed the following: The cells had lost their staining property. There remained only the ghost of alveoli, with solid masses of pus.

Dog A 1 (4).—The animal was killed on the seventh day. Abscess of the lung was found. There was a definite thickening of the remains of the alveolar wall about the abscess. Pieces of bronchus and lung tissue were removed at the time of operation and cultures were made from them. No growth was obtained. Pus obtained from the abscess yielded no organism.

Fig. 3.—High power magnification. Photomicrograph of abscess noted in figs 1 and 2.

Dog A 2 (5).—The animal was killed on the seventh day. Abscess of the lung was found. A culture of a portion of excised bronchus removed at operation showed no growth.

Dog B 25 (6).—The animal was killed on the twelfth day. Necropsy showed abscess of the lung (figs. 4 and 5). The right lung, which had been operated on, was riddled with abscesses. The wound was healed, but not as firmly as usual. The pleural cavity was free. The microscopic observations were those of typical abscess formation.

Dog B 17 (8).—The animal was killed on the fifth day. There was no evidence of abscess of the lung. The lung was grossly firm. The incision had healed.

There were no adhesions. There was considerable induration of the lung tissue distal to the incision. A large bronchus which had been intentionally cut across was plugged. There was a firm scar and no abscess.

Microscopic Examination.—There were exudate in the alveoli and blood in the region of the incision. There was not the actual connective tissue scar proliferation that was noted in the lungs in which the pulmonary artery was not ligated. The plugged bronchus contained cellular débris and pus cells.

Dogs 16 A (9) and B 3 (10).—Both dogs were killed seven days after the operation and both had an abscess in the lobe of the lung which had undergone operation.

Fig. 4 (dog B 25).—Gross section of the right lower lobe cut in half, showing large abscess of the lung.

COMMENT

In a series of experiments in which ten dogs were employed, the pulmonary artery to the right lower lobe was ligated. The pulmonary parenchyma of the same lobe was incised for 3 inches (7.6 cm.). The incision included a large bronchus. An abscess of the lung (the right lower lobe) developed in eight of ten instances when the pulmonary artery was ligated and the pulmonary parenchyma incised and sutured. The scar healed in every instance. In no case did empyema develop. One dog showed the remains of an old abscess, another a lesion which was considered a healed abscess. Multiple abscesses in the lobe oper-

ated on were noted only once. The abscess was always found in the lobe which had been operated on, and never elsewhere. Its diameter in a few instances corresponded to the length of the scar, but the latter, as already noted, was free in every instance. It is to be noted that the bronchi which were cut across were allowed to retract. In three instances in which abscess of the lung developed, a portion of bronchus was excised at the time of operation and showed no growth. In two of these instances, culture of the abscess yielded only spore formers on one occasion. There was no growth.

Changes in the lung following ligation of the pulmonary artery have been described by Schlaepfer and others. He noted fibrosis of the lung following ligation of the pulmonary artery, especially when this proce-

Fig. 5 (dog B 25).—Photomicrograph of high power magnification of abscess noted in fig. 4.

dure was combined with phrenicotomy and with partial occlusion of the pulmonary veins. Schlaepfer observed that after ligation of the pulmonary artery a stasis takes place on the alveolar side of the pulmonary veins with a resultant exudation of serum, erythrocytes and leukocytes into the alveoli and interstitial tissue. At the beginning there is also an increased flow of lymph.

William Snow Miller long ago demonstrated the fact that the bronchial blood vessels are directly connected with the pulmonary vein. That fine, barely demonstrable, yet adequate, anastomoses may take place between arteries and veins was shown by Hayer.

Virchow's investigations on hemorrhagic infarcts of the lung led him to conclude that the interruption of a branch of the pulmonary

artery in no way influenced the nutrition of the pulmonary parenchyma. The bronchial arteries apparently give off important nutrient branches. This view is not in accord with that of Cohnheim and Litten, who did not feel that the bronchial arteries were absolutely adequate in this respect.

Chjrzontschewsky experimentally injected a dye into the circulation after having ligated the main branch of the left pulmonary artery. He found the substance not only in the bronchial arteries, but also in the branches of the artery which had been tied off and also in the veins. He therefore concluded that this demonstrated the presence of a capillary network. Küttner's observations in this respect were similar.

Konaschko was able to prove rather conclusively that adequate communications exist between the pulmonary artery and the bronchial arteries. He was able to fill the mediastinal pleural branches of the bronchial artery by injecting the pulmonary artery. He also observed that similar fine communications existed in the walls of the bronchi. His observations in general substantiate many of those previously made by Zuckerkandl.

It would therefore seem rather certain that adequate nutrition of the pulmonary parenchyma exists following ligation of the pulmonary artery, at any rate sufficiently adequate nutrition, under previously normal conditions, to prevent the occurrence of a hemorrhagic infarct. It is interesting in this connection to consider the work of Rose, who considered the lung as essentially a vascular organ.

We observed no appreciable increase in fibrous connective tissue in the lung over periods up to four weeks following ligation of the pulmonary artery. No abscess formation followed this procedure.

The corresponding lobe did not decrease in size, nor did the alveoli appear to be smaller. Other changes observed corresponded to those already described by Schlaepfer.

Hasslinger and Sternberg studied the flora of the tracheobronchial tree in the living person. These investigators also studied the flora of the tracheobronchial tract of the dog. They were able to show that use of cocaine or of cocaine and epinephrine somewhat retards the growth of bacteria from twenty-four to twenty-eight hours but does not kill them. They observed their cultures for eight days. Their technic was extremely careful and was carried out through a bronchoscope. They recovered streptococci, staphylococci, rods and various saprophytes from the subglottic space of seven dogs. The secretions from the trachea beyond the bifurcation and from the main bronchi were in every instance sterile, both in patients and in the dogs.

In our experiments, six dogs were killed on the seventh day. All these dogs had developed an abscess of the lung, one of which was

healed. Two dogs were killed after one month. One of the dog's lungs in this group showed a healed abscess, the lungs of the remaining dogs, no abscess. One dog was killed on the fifth day and showed no evidence of abscess of the lung. The tenth dog was killed on the twelfth day and showed multiple abscesses of the lung. We injected known organisms into a bronchus and then ligated the pulmonary artery in one instance. We were able to recover the same organism from the pneumonic areas which resulted. As to the raison d'être, we can at the present time only theorize. Simple incision and suture of pulmonary parenchyma is not followed by the development of an abscess of the lung. Similarly, simple ligation of the pulmonary artery shows no such change. The combination of both procedures, in our experience, frequently results in the development of an abscess of the lung. From the experience of Haslinger and Sternberg and from our own in three instances, we know that the bronchi are apparently normally sterile. It is possible, however, that the trauma to the lung puts it somewhat at rest, and therefore it may not be unlikely that organisms may reach the lung, either from the mouth or through the circulation. Be this as it may, the contents of the cut bronchus can pour into the parenchyma. Such bronchi have been observed to be plugged with pus. The presence of blood from the original operation must also be considered as a possible factor. The abscess formation could not be attributed to faulty technic or to a foreign body, such as silk, which was the suture material used. The ligation of the pulmonary artery may slow the circulation somewhat. Our bacteriologic studies are as yet incomplete. No virulent organisms have been recovered, however, from the abscesses which resulted. The lobes operated on as described functioned perfectly. We thus have a combination of circulatory and "aspiratory" factors, and, as has been suggested by others who have worked with noninfected bland emboli, it would perhaps seem that abscess of the lung, like so many other lesions, may not only result from several mechanisms, but that its formation requires a combination of factors.

SUMMARY

1. In ten dogs, ligation of the pulmonary artery to the right lower lobe and simple incision and suture of the pulmonary parenchyma of the corresponding lobe was followed by the formation of an abscess of the lung in eight instances.

2. No appreciable increase in fibrous connective tissue was observed in the lung over periods up to four weeks following ligation of the pulmonary artery.

3. The corresponding lobe did not decrease in size, nor did the alveoli appear to be smaller.

4. Simple incision and suture of the pulmonary parenchyma resulted in a scar which resembled a scar elsewhere in the body and was not followed by the development of an abscess of the lung. It is to be noted in this connection that phrenicotomy performed on the corresponding side apparently in no way influenced the end result.

BIBLIOGRAPHY

Chjrzontschewsky, quoted by Konaschko, P. J.: Ztschr. f. Anat. u. Entwicklungs **78**:136, 1926.

Cohnheim, J., and Litten, M.: Ueber die Fabgen der Embolie der Lungenarterien, Virchows Arch. f. path. Anat. **65**:99, 1875.

Haslinger, F., and Sternberg, H.: The Flora des Tracheobronchialbaumes am Lebenden, Ztschr. f. Hals-, Nasen- u. Ohrenh. **16**:108, 1926.

Hoyer, H.: Ueber Unmittelbare Einmündung kleinster Arterien in Gefässaste Charakters, Arch. f. mikr. Anat. **13**:603, 1877.

Konaschko, P. J.: Ueber Anastamosen zwischen der Arteria pulmonalis und den Arteria bronchiales, Ztschr. f. Anat. u. Entwicklungs **78**:136, 1926.

Küttner: Beitrag zur kenntnis der Kreislaugsverhältnisse der Säugethierlunge, Virchows Arch. f. path. Anat. **73**:476, 1878.

Miller, W. S.: The Arrangement of the Bronchial Blood Vessels, Anat. Anz. **28**:432, 1906.

Rose, S. B.: Finer Structure of Lung with Special Reference to Its Vascular Character and Its Pathologic Significance, Arch. Path. **6**:36 (July) 1928.

Schlaepfer, K.: Fibrosis of the Lung following Ligation of the Pulmonary Artery, Arch. Surg. **6**:358 (Jan.) 1923.

Virchow, quoted by Konaschko: Ztschr. f. Anat. u. Entwicklungs **78**:136, 1926.

Zuckerkandl, E.: Ueber die Verbindungen zwischen der Arteriellen Gefässen der menschliches Lunges, Sitzungsb. d. Akad. d. Wissensch. **87**:171, 1883.

5. THE ORIGIN OF SCAR TISSUE IN HEALING OF THE LUNG*

I. Y. OLCH, M.D.
AND
HARRY C. BALLON, M.D.
ST. LOUIS

These studies are concerned with the origin of scar tissue in healing of the lung. They were undertaken chiefly because of the recent experiences of others who questioned the previous conception of the development and structure of the lung. All experiments were performed on dogs under sterile conditions. The positive pressure apparatus of Erlanger-Gessel was employed. The first group of experiments illustrate the effect of simple incision and suture of pulmonary parenchyma.

SIMPLE INCISION AND SUTURE OF PULMONARY PARENCHYMA

Dog 138.—A single incision, 2 inches (5.0 cm.) long, which ran at right angles to the axis of the main bronchus was made in the right lower lobe of a dog's lung on Dec. 31, 1928. This incision included several blood vessels and bronchi. The animal showed no discomfort and was killed on the tenth day, by means of an overdose of ether. The chest cavity was reopened under positive pressure. The incised lobe was previously observed to function perfectly. There were no adhesions; the suture line had healed perfectly.

Microscopic Examination.—Microscopically, the lung was normal throughout in every respect. There were no abnormal cells and no exudate. The scar resembled a normal scar which might be found on any other part of the body. The pulmonary parenchyma distal and proximal to the scar looked alike. There was only slight local compression of alveoli, which could be attributed to the contraction of the scar.

Dog 139.—Another dog operated on as described was killed on the fifteenth day. A few fine adhesions could be noted, but only where the lung had been handled by gauze, which was away from the incision. The incision was smooth. The entire lung contained air. There were no evidences of mediastinal or subcutaneous emphysema.

Microscopic Examination.—Smaller bronchi were observed to have been cut across and were somewhat collapsed. There was slight pulmonary emphysema about the scar, but this was in all probability due to the fact that the lung had after removal immediately been fixed by injecting a diluted solution of formaldehyde into the bronchial tree. There was active proliferation about the scar. The origin of the scar tissue could not be definitely determined.

Another dog operated on in a similar manner developed an empyema and died on the fourth day. The line of incision had not broken down. No bronchial fistulas could be demonstrated. A fistula may, however, have been coated over by exudate. The right lung showed evidences of pneumonia. There was no abscess formation in the lung.

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* From the Department of Surgery, Washington University Medical School and Barnes Hospital.

The fourth dog in this series of experiments was killed on the fifth day. The observations were essentially those noted in the first two experiments.

The suture line was in a moderately advanced stage of healing. A slight extravasation of blood into the wound could be noted. Some small bronchi which had been previously cut across were caught in the scar and were partially collapsed. All adjacent blood vessels were dilated and filled with blood.

Comment.—A scar in the lung, the result of a simple incision and suture of pulmonary parenchyma, resembles a scar elsewhere on the

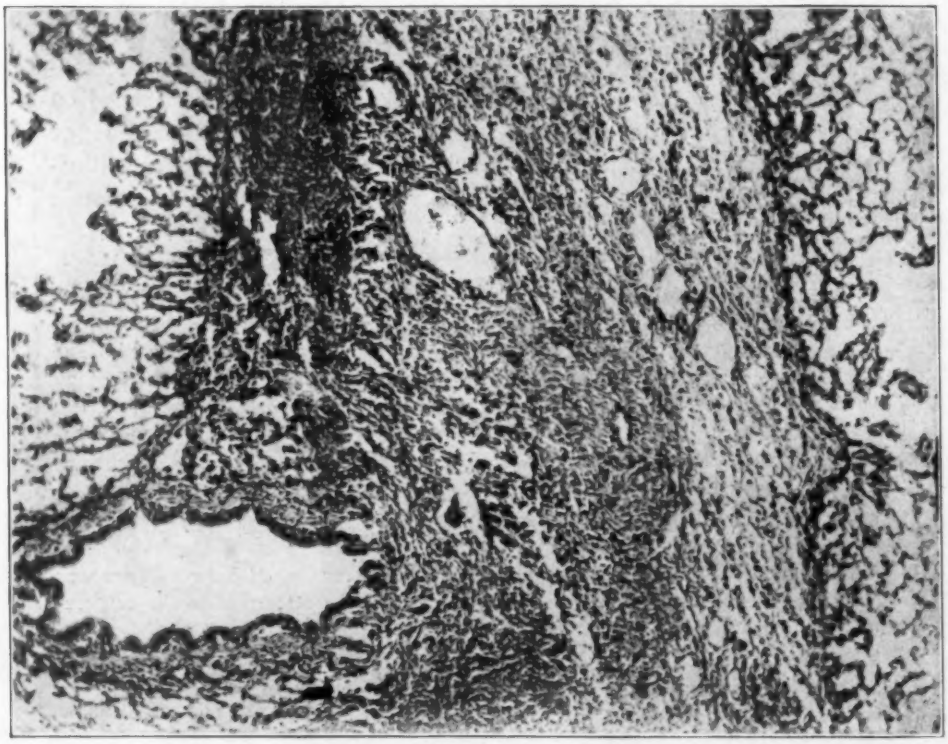

Fig. 1 (dog 138).—Photomicrograph showing a ten day old scar in lung. This scar followed a simple incision and suture of the pulmonary parenchyma. It is made up of connective tissue and shows moderate round cell infiltration. Normal air-containing alveoli are seen on either side of the scar. An adjacent bronchus is unaffected.

body. Except for the presence of adjacent collapsed alveoli, which are alveoli caught in the contracting and retracting scar, no differences on ordinary histologic examination can be noted. The usual methods of examination do not permit one to ascertain the origin and source of the scar tissue. Simple incision and suture of normal lung tissue under sterile conditions is not followed by abscess formation.

SIMPLE INCISION AND SUTURE OF PULMONARY PARENCHYMA FOLLOWED BY INTRATRACHEAL INJECTION OF TRYPAN BLUE

The following experiments differ from those already recorded only in that on the first, second, third, fourth and fifth postoperative days the dogs experimented on received an intratracheal injection of 5 cc. of a 1 per cent solution of trypan blue. This first dog was killed on the tenth day. This was exactly three days after the last injection of trypan blue.

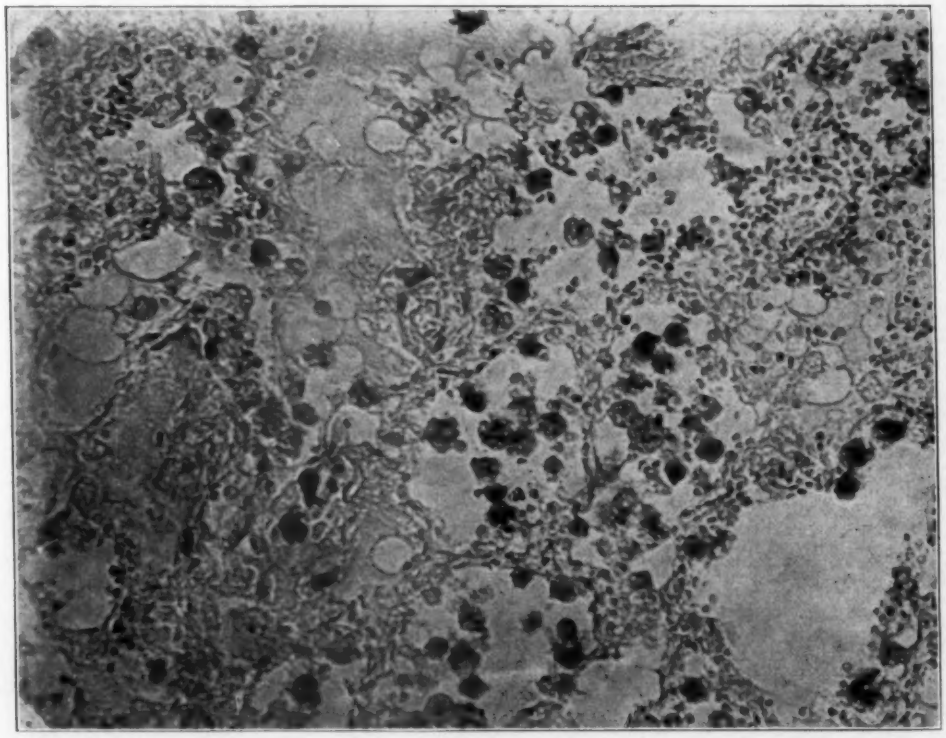

Fig. 2.—Note macrophages containing trypan blue. The smaller cells seen in the right upper quadrant are erythrocytes. Low magnification.

Grossly, such a lung was nonadherent. The suture line was clean and healed. Most of the trypan blue was in the right lower lobe; but relatively little was in the region operated on, namely, the right middle lobe. The lung felt firmer and more solid than normal.

Microscopic Examination.—The incision in the lung showed all the signs of active healing. Considerable patchy cellular exudate (red blood cells and mononuclear cells) could be observed throughout the whole right lung; this was most marked in the "incised" lung, particularly in the areas which contained trypan blue.

Dog 340.—The right lower lobe was incised and sutured. The subsequent technic was as already noted.

On March 11, this dog was given 20 cc. of trypan blue intratracheally.

On March 12, the left side of the chest was opened and the left lower lobe was operated on in a similar manner. A wedge of lung tissue was excised from this lobe. On March 13, 14 and 15, the animal was given doses of 10 cc. of trypan blue intratracheally in an attempt to demonstrate the histiocyte reaction following the injection of this dye.

The dog was killed on March 16, that is, five weeks after the first operation and four days after the second operation. Both lungs were blue and fairly firm. A hematoma could be seen in the left lower lobe. There was no inflammatory reaction about the hematoma, which lay distal to the scar which was four days old.

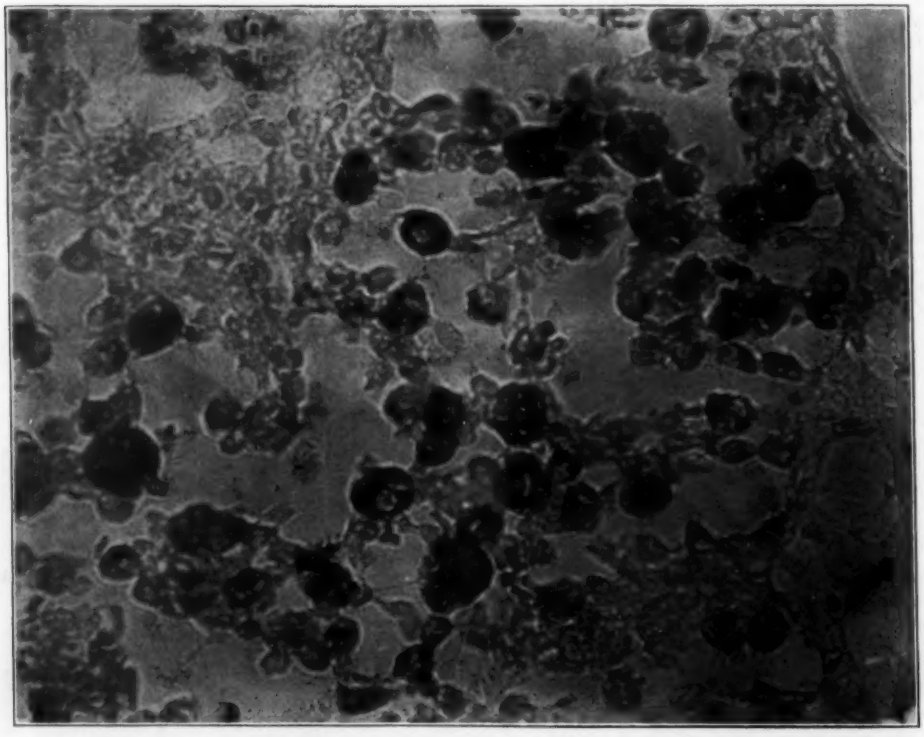

Fig. 3.—Photomicrograph of same field as that in figure 2. High magnification.

The question might be raised as to whether additional factors, such as slowing of the circulation, might not under favorable circumstances render such a hematoma susceptible to secondary infection.

The scars in both lungs were healed. No abscesses could be noted.

Microscopic Examination.—Section A, taken from the left lower lobe at the time of the second operation, which was performed twenty-four hours after the injection of trypan blue, showed considerable exudation of cells of all kinds.

Sections from the left lower lobe, taken four days later, showed that the exudate was more extensive than that noted in section A. It is to be appreciated, however, that the dog in the meantime received additional injections of trypan blue. More pigment was therefore to be observed in the cells, many of which seemed to plug the alveoli.

Sections taken from the right lung at necropsy showed a healed scar. There were still evidences of the exudation of cells, engorgement of interalveolar capillaries with blood, and areas in which the general arrangement of inflammatory cells resembled pneumonia. A microscopic section from the right upper lobe gave the same picture of a "patchy pneumonia."

No pigment cells were observed in the scar.

Dog 300.—On Feb. 22, 1929, a simple incision and suture of the pulmonary parenchyma and intrathoracic phrenicotomy on the right side were done. On March 11, 20 cc. of a 1 per cent solution of trypan blue was injected intratracheally. On March 12, a wedge was cut out of the left lung. On this occasion the lungs were quite blue and felt irregularly firm, much more so than a normal lung. From March 12 to 15, 10 cc. of trypan blue was given intratracheally. The animal was killed on March 16, which was twenty-two days after the first operation and four days after the second operation, which was on the left side.

The right side of the diaphragm showed the effects of the phrenicectomy. It was thin and atrophic.

There was a perfect scar in the right lung. There was some hemorrhagic discoloration about the scar in the left lung.

No abscess formation or pneumonic process could be noted in either lung.

Microscopic Examination.—A specimen taken at second operation showed what would be expected twenty-four hours after the injection of trypan blue. There was a patchy pneumonic-like process. The blood vessels were engorged. Patchy exudation was most marked about the bronchi, which also contained inflammatory cells.

The injection of trypan blue into the lung produces patchy pneumonic-like areas. In these areas only little trypan blue can, however, be observed. Only an occasional phagocyte which had ingested trypan blue was observed in the areas from which sections were taken. Yet such an area of the lung is quite blue, firm and, as already mentioned, shows microscopically only a little trypan blue.

A section taken from the left lung (the same site as that of the aforementioned section) four days after the second operation showed active fibrous reaction. There was considerable leakage of blood into the wound, around which fibrous tissue reaction attempting to wall it off could be noted. There were also many inflammatory cells here. The lung tissue about the scar contained air. There was a large number of scattered cells in the alveoli and mononuclear cells which appeared to come from the alveolar wall. There were practically no pigment cells in the scar tissue.

Sections from the right lung, which was operated on five weeks previously, showed complete healing of the scar. Many cells loaded with pigment were to be seen in the alveoli, also a few in the scar.

Section 300 E was taken from the right upper lobe, which was normal except that it had received injections of trypan blue. This lung showed the "pneumonic-like" processes alluded to, and many "dust cells" which contained blue pigment.

COMMENT

In the earlier experiences with vital staining in the study of the reticulo-endothelial system of the body, it was noted that the lungs remained singularly free from pigment-laden macrophages or showed just a few such cells after the intravenous or intraperitoneal injection of various dyes. Certainly such lungs showed proportionately much less

pigment than was found in other organs of the body, notably the liver. The few pigment cells found in the lung were grouped about the larger blood vessels. From these observations it was concluded that the macrophages did not originate in the lungs, and that these organs could not be classed as a part of, or considered to contribute to, the reticulo-endothelial system. Because the pigment cells seen in the lung were about the blood vessels, it was thought that they arose from the capillary endothelium.

Fried [1] more recently reconsidered the macrophage reaction in the lungs by injecting vital dye and oil intratracheally. He found that there is abundant proliferation into the alveoli of mononuclear cells laden with pigment after the injection. He showed that they came from the cells lining the alveoli. They corresponded morphologically and physiologically to the macrophages of the reticulo-endothelial system. He thus concluded that the lung has an active defense mechanism concerned with the proliferation of these cells, and that the alveoli are not lined with epithelium but with cells having the properties of macrophages. The latter, then, do not come from the capillary endothelium but from the alveoli. The reasons why this reaction is not seen after intravenous or intraperitoneal injections of vital dye are: (1) The dye is diluted; (2) the Kupffer cells of the liver pick it up and so prevent its entering the lung, and (3) a large part of the dye is excreted in the feces, urine and bile. Other observations on the lungs so treated were: thickening of the alveolar walls; the filling up of alveoli with these cells, and their coalescence to form patches resembling those seen in bronchopneumonia.

In trying to determine the origin of the cells forming the scar in the parenchyma of the lung, we wondered as to the rôle played by the cells that line the alveoli and proliferate abundantly. The thought occurred that they contribute to the formation of the scar. Dogs therefore received intratracheal and intravenous injections of 10 cc. of a 1 per cent solution of trypan blue. The injection was given slowly. The animals were held in the upright position while the dye was given, and for ten minutes afterward. On the following day, the chest was opened under ether anesthesia administered by means of the positive pressure apparatus. The lungs were found to be somewhat firmer than usual and to be stained in varying intensity in irregular patches. The incision into the parenchyma was always made in the right lower lobe as described. A wedge of lung tissue was cut out from the edge of the incision for microscopic study at the time of operation. The wounds in the parenchyma and chest were then sutured. The chest was closed in layers. As all incisions in the larger muscles were made in the direc-

1. Fried, B. M.: The Defensive and Metabolic Apparatus of the Lungs: The Lungs and the Macrophage System, Arch. Path. **6**:1008 (Dec.) 1928.

tion of their fibers, which were then retracted, a good closure was insured. On the first, second and third postoperative days, these dogs each received 10 cc. of the 1 per cent trypan blue solution intratracheally. They were killed on the fifth or seventh day after operation. Just before death the lungs were functioning, and no adhesions were seen at the suture line. The lungs were firmer than normal and stained irregularly with the blue dye. On section, no abscesses were found, and the pinkish-white scar could easily be made out.

The microscopic observations in these lungs coincided with those described by Fried:[2] areas of proliferation of alveolar lining cells, the presence of pigment in these cells, thickening of the alveoli and coalescence of areas of proliferation into pneumonia-like patches. The striking observation, as far as we are concerned, was the absence of macrophages, at least of pigment-containing cells, even in the early scars.

According to Fried's observations, we should have found large numbers of these phagocytic cells among the devitalized cells and the blood pigment found in the edges of the incision into the parenchyma of the lung. A few such cells were seen near the scar but not in it. Evidently such phagocytic cells do not wander far from the alveoli in which they arise, or else the stimulus of simply incising the lung is not sufficient to attract them to the scar. We believe that the scar which develops following a simple incision into the lung is formed from the fixed tissue cells arising from the supporting framework of the lung, and that the cells lining the alveoli do not contribute to this scar. The function of the macrophages in this connection seems to be rather more one of defense against organisms or particulate matter introduced directly into the alveoli.

SUMMARY

Some observations have been made concerning the origin of the scar tissue in healing of the lung. A scar in the lung, the result of a simple incision and suture of pulmonary parenchyma, resembles a scar elsewhere in the body. The injection of trypan blue into the lung produces patchy, pneumonic-like areas. Practically no pigment cells are to be found in the scar, even early in the process. It would seem that the scar arises from the fixed tissue cells of the supporting framework of the lung, and that the function of the macrophages is rather one of defense against organisms or particulate matter which are introduced into the alveoli.

2. Fried, B. M.: The Origin of Histiocytes (Macrophages) in the Lungs, Arch. Path. **3**:751 (May) 1927.

6. THE BACTERIAL FLORA OF TREATED AND UNTREATED ABCESSES OF THE LUNG*

PHILIP L. VARNEY, M.S.
ST. LOUIS

In the majority of cases of chronic abscesses of the lung reported in the literature, the bacteriologic study has been limited to the preparation and examination of stained smears for the presence primarily of fusiform bacilli and spirochetes, the diagnosis being made on the satisfactory demonstration of these organisms in conjunction with the clinical observations. Chief clinical interest in the so-called "etiology" of this condition has been in whether it results primarily from the aspiration of infected material from the mouth and nasal passages or from the introduction of infected emboli into the blood stream. In contradistinction to the study of the predisposing factors, complete bacteriologic studies of the bacterial flora in these cases have been surprisingly few in number.

In pathologic conditions such as abscesses of the lung, it is extremely difficult to select any one organism or even a number of organisms as the etiologic factors. It is of importance, however, to study the bacteriologic flora of such abscesses, as through this study one may possibly determine the source of infection and be enabled to guard against the initial infection.

In many of the bacteriologic studies made, little information has been obtained because of the failure of investigators to include in their technical methods anaerobic as well as aerobic methods of study. In the last few years increasing emphasis has been directed toward the rôle of anaerobes in the production of abscesses of the lung, this evidence all pointing toward the importance of a proper study of the anaerobic as well as of the aerobic flora of material from these lesions. The bacterial flora of abscesses of the lung can be determined only by an increasing number of careful studies of infected material, in which the importance of anaerobic as well as aerobic flora is taken into consideration.

The data on which the present report is based were secured from the study of a large series of cases of abscesses of the lung in Barnes Hospital, twenty-seven of which were selected as meeting what were believed to be the primary requirements for an accurate study of the bacterial flora of this condition; namely, freedom of the material studied from external contamination, and an immediate plating of the material following its withdrawal from the body.

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* From the Department of Bacteriology and Immunology of the Washington University School of Medicine, and Barnes Hospital.

The material from these patients was secured and prepared for study in the following ways: (1) At Operation: In these cases, the pus was aspirated under aseptic precautions the moment the pus cavity was opened, immediately placed in a sterile tube kept at 37 C., and without further delay taken to the laboratory for examination. Material from several of these patients was also introduced into the lungs of dogs in an effort to produce abscesses of the lung by experimental methods.[1] Pus secured in this manner was not treated in any way other than to wash thoroughly, in several changes of warm sterile saline solution, any granules which might be found, in order to remove liquid pus which might adhere. Both the granules and the liquid portions of the pus were then separately plated on blood agar, and immediately incubated at 37 C., under both aerobic and anaerobic conditions. Plates were incubated under anaerobic conditions in the phosphorus anaerobic jar previously described by me.[2] Smears of both granules, if present, and the liquid pus were prepared and examined after staining by Gram's method, with gentian violet, and by the method of Fontana.

(2) By Postural Drainage: Following a cleaning of the mouth with a suitable wash, the patient was inclined with the head lower than the feet, so that the abscess pus drained freely from the mouth. The first portions were discarded and the material to be studied was collected in a sterile container, transferred immediately to the laboratory and treated as described.

(3) By Coughing While in a Reclining Position: The mouth was washed as before; the patient was turned on his side and was instructed to cough. By this method, certain samples of pus were found to be grossly contaminated with saliva and sputum from the upper respiratory passages, often sufficient in amount to cause it to separate into three layers as is often described in the literature. Such material is almost worthless for examination. In some cases, therefore, repeated samples were secured before a satisfactory one was obtained. If the material appeared to be largely saliva, it was discarded and another sample was secured. Only when a very small amount of saliva was present in the pus was the sample deemed representative enough to be used in this study. On arrival at the laboratory, the sample was placed in thin layers in a petri dish, the pus being separated from any saliva present, and thoroughly washed in repeated changes of sterile saline solution. The granules were picked out by means of a needle and treated similarly, following which the usual smears and cultures were made.

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1. Allen, Duff S.: Etiology of Abscess of the Lung, Arch. Surg. **16**:179 (Jan.) 1928.

2. Varney, Philip L.: A Simple Method for Cultivating Anaerobes by Means of Phosphorus, J. Lab. & Clin. Med. **11**:1183, 1926.

(4) By Swabbing, Following Operation: This method was used when it was found desirable to check the progress of the disease following operation, and when none of the methods previously described could be utilized because of their danger. A sterile, tightly rolled cotton swab was introduced deep into the wound; the patient was told to exhale, and the pus which was forced out was collected on the swab. The amount of material secured in this manner was often very small, and a decided change in the bacterial flora could often be demonstrated.

McNeill [3] and others have reported the rapid disappearance of spirochetes from saliva and pus secured from abscesses of the lung when the material is allowed to stand for a few minutes or hours in an open container. In the early stages of this work, therefore, before this phenomenon could be investigated, the first procedure on securing the sample was to prepare smears of it, in the belief that otherwise no spirochetes might be found. Early results seemed to substantiate the observations of these investigators; like them, I could find no spirochetes in the sputum after it had stood for a short interval following its withdrawal from the body. This fact necessitated, therefore, the rapid preparation of smears before cultures were made. In a later study relative to the disappearance of spirochetes from the pus, it was found that they could usually be demonstrated, if present in more than minute numbers in the original material, for as long as forty-eight hours after their withdrawal from the body, and that by preparing smears several hours after the withdrawal of the pus one could demonstrate them in their original concentration, providing that the proper material was chosen for examination. Most samples of unaltered pus from abscesses of the lung are rather tenacious or sticky, and any suspended matter will remain evenly distributed throughout. The spirochetes in the samples of pus studied in this series of cases were found almost exclusively in small, minute granules, which were soft to hard, cheesy or calcareous, white to dark brown masses composed of bacteria and which varied in size from a fraction of a millimeter to several millimeters in diameter. These granules are almost invariably present in chronic or far advanced cases of abscesses of the lung and bronchiectasis. They usually have a foul, intense odor, reminiscent of that produced by *Bacillus melaninogenicum*, one of the organisms to be described. When examined under the microscope these masses are often found to consist of enormous numbers of spirochetes, which in wet preparations are actively motile, mixed with streptococci and varying numbers of gram-negative and gram-positive cocci of several species. Due to the semiliquid state of the material surrounding them, these granules usually remain evenly

3. McNeill, Clyde: Pulmonary Infection with the Spirochaetae and Fusiform Bacilli of Vincent, Bull. Johns Hopkins Hosp. **35**:368, 1924.

suspended for a short period of time following the withdrawal of the pus, and are readily withdrawn by the inoculating loop when the material is smeared out, so that if any granules are present spirochetes will usually be found. After standing for a short period of time, however, the pus becomes quite liquid, owing to the action of its proteolytic enzymes, and as a consequence the granules settle out, carrying the spirochetes with them. It is therefore of the greatest importance to examine the pus for the presence of these granules, for it is here and usually only here that the spirochetes may be found. If they are apparently discovered in the liquid portions of the pus, it will usually be found that one has accidentally picked up a small granule and smeared it out together with the liquid portions of the pus. Knowing the location of the spirochetes, and that they can still be found many hours after the withdrawal of the pus, it is of advantage first to plate out the material as rapidly as possible, thus giving no chance for a change in the bacterial flora, and subsequently to prepare the smears immediately after the plating. In this work, the material was first thoroughly washed; then the granules and liquid portions were plated separately on special blood agar, consisting of 1 per cent proteose peptone, 0.5 per cent sodium chloride, 0.3 per cent beef extract and 1.7 per cent dried agar-agar adjusted to p_H 7.4. In each of the cases in this series, the material was plated within fifteen minutes after its withdrawal from the body, and most of the platings were completed in from five to ten minutes; thus there was little chance for any change in the bacterial flora, through either the multiplication or the death of any of the micro-organisms present. It was found by cultural tests that the fusiform bacilli and spirochetes often remained alive for as long as twenty-four hours after the collection of the samples; hence it is safe to assume that the brief exposure of the samples to air had little deleterious effect on the anaerobic flora.

The pus or granules were streaked out on plates by means of a special machine streaking,[4] as it had been found almost impossible to get representative results on repeated culture when hand streaking methods were employed. When streaked by the aid of the machine, the tenacious, tough material could be distributed evenly, owing to the greater pressure of the contaminated inoculating spatula which could safely be applied against the agar as compared with the pressure possible with hand streaking; this method thoroughly liberated the imprisoned bacteria and gave rise to an eveness and degree of distribution not possible to obtain by hand methods. Many of the bacteria repeatedly found in large numbers following machine streaking could scarcely be found

4. Varney, Philip L.: A New Spiral Streak Plate Method of Isolating Bacteria by Means of an Inoculating Machine, J. Infect. Dis. **41**:190, 1927.

following hand streaking methods. This was especially true in the study of the granular masses, for these must be subjected to a severe grinding action before they become sufficiently broken up to form well isolated colonies. Owing to this lesser grinding action, hand streaking methods gave entirely different and much less consistent results than those produced by machine streaking, and fusiform bacilli were often not found on plates streaked from material that was positive by microscopic tests.

Aerobic plates were examined in twenty-four hours and their bacterial population recorded, following which they were reincubated twenty-four hours longer and reexamined to see if any further changes had resulted. Changes seldom occur after forty-eight hours, however, even though the plates are incubated for as long as one week, and all the essential data can be secured within this period of time. The anaerobic plates incubated in the phosphorus anaerobic jar were first examined after forty-eight hours, as the colonies of fusiform bacilli, streptococci and pneumococci, if present, are most characteristic at this time. They were reexamined after a period of incubation of from one to two weeks for the final record as to the presence of *B. melaninogenicum* and any spirochetes which might have grown, or of any other slowly growing organism.

In this work, an attempt was made to study as closely as possible the aerobic and anaerobic bacterial flora present in the pus from chronic abscesses of the lung, especially in regard to the presence of *Bacillus fusiformis,* spirochetes, streptococci and *B. melaninogenicum.* While the first three organisms are familiar to all, the latter organism is comparatively unknown; hence a brief description of it may be of interest.

BACILLUS MELANINOGENICUM

Oliver and Wherry [5] were the first investigators to study and name this organism. They noticed in cultures from the human body a minute, strictly anaerobic, nonmotile, polymorphic gram-negative rod measuring 0.8 by 1 to 3 microns, which, when grown under anaerobic conditions on mediums containing hemoglobin, produced after rather an extended period of incubation intensely black colonies which rapidly removed the last vestiges of hemoglobin from the plate, leaving it entirely colorless, similar to a plain agar plate. Because of the nature of the pigment, which they believed to be melanin, they named the organism *B. melaninogenicum.* Burdon,[6] who has worked extensively with the organism in this laboratory, found it difficult by plate methods of isolation and

5. Oliver, W. W., and Wherry, W. B.: Notes on Some Bacterial Parasites of the Human Mucous Membranes, J. Infect. Dis. **28**:341, 1921.

6. Burdon, Kenneth L.: Bacterium Melaninogenicum from Normal and Pathologic Tissues, J. Infect. Dis. **42**:161, 1928.

study to isolate the organism in pure culture, as it grows in symbiosis with other organisms to a remarkable extent. He found the growth of strictly pure cultures to be slow, and that when so growing, the hemoglobin substrate was destroyed only to a slight extent. A small amount of contamination, however, far too little and in too intimate a mixture to be detected by a casual bacteriologic examination, would markedly stimulate the rate of growth of the organism, as well as enable it to hemolyze blood and destroy all color in blood agar plates within a short time.

Burdon secured rapid growth in mixed cultures; the development of the organism was indicated by the formation of a dark brown or black colony containing large amounts of an amorphous, extracellular, melanin-like pigment. In most cases the first trace of melanin was apparent after five or six days in primary cultures, although if the organisms were numerous the pigment might show up as early as the second day (forty hours) or, if the organisms were few, as late as the sixteenth day. The pigmented colonies of the organism grew in, on, over the top and around the colonies of other bacteria, which reached their maximum development long before the colonies of *B. melaninogenicum*.

Burdon found the organisms rather widely distributed about the body, and found them also in certain lesions of the lower animals, such as dogs and guinea-pigs. He found a close correlation between the number of colonies of *B. melaninogenicum* growing in the culture and the cleanliness of the organ from which the culture was made. The organism was present in all mouths; while present in only small numbers in normal mouths, so that a long and careful search was required to find it, it was exceedingly numerous in septic conditions such as pyorrhea alveolaris, in which it could be and was used as an index of the severity of the lesions.

The organisms were frequently found about the genitalia of both male and female patients, the relative number present being directly proportional to the lack of cleanliness of the parts or to the severity of the lesions, if any were present. In patients from the ward or the clinic, the organisms were abundant, but in private patients, who were obviously much cleaner as determined by inspection, few organisms were found. Schwarz and Dieckmann[7] obtained *B. melaninogenicum* from nine blood cultures of patients suffering with puerperal fever, the organisms being identified by Burdon, and found the organism in 90 per cent of their routine uterine cultures.

In a study that I made, in 1926, of sixteen excised tonsils, reported by Burdon,[6] *B. melaninogenicum* was found in every case, the plates

7. Schwarz, O. H., and Dieckmann, W. J.: Puerperal Infection Due to Anaerobic Streptococci, Am. J. Obst. & Gynec. **13**:467, 1927.

made from the infected tissues showing from only a few to a great majority of colonies of the organism. Here again the numbers were proportional to the severity of infection, as determined by a study of the gross lesions of the excised tissues. Badly infected tonsils, especially those also containing large tonsillar granules within their crypts, showed large numbers of the organisms, whereas only a few black organisms were found in the apparently normal tonsils. Tonsillar granules were frequently found in the severely infected tonsils, and it was in these granules that *B. melaninogenicum* was most abundant. Some of these granules were so large that, unless preventive measures had been used, they might readily have been aspirated during operation, thus possibly giving rise to infections of the lungs. I found the flora of these granules to be almost exactly the same as that present in granular material in pus from abscesses of the lung, and it is my belief that abscesses of the lung following tonsillectomies may very likely result from the aspiration of such material.

No black organisms were found in cultures from the hands or fingernails of five persons examined, or from the axillae of five persons examined.

Fecal material from four infants less than 14 days old contained considerable numbers of *B. melaninogenicum,* but specimens from four other infants were negative. Cultures were taken from the feces of fifteen adults; ten cultures were positive, and all showed a fairly large number of the organisms, indicating that once they pass into the alimentary canal, they may persist throughout the entire tract.

Both aerobic and anaerobic cultures were made in a small series of cases of cervical abscesses studied at Barnes Hospital. *B. melaninogenicum* was found in every case in rather large numbers, in some cases constituting a majority of the organisms found. The pus was a deep chocolate-brown, with an odor similar to that produced by mixed cultures of *B. melaninogenicum.* In addition to this organism, fusiform bacilli, spirochetes and streptococci were also encountered in these lesions. In no case could the pus have been differentiated physically or bacteriologically from that encountered in chronic or severe abscesses of the lung.

It may thus be seen that *B. melaninogenicum,* while rather widely distributed, is closely associated with the presence of pathologic conditions and that, owing to its widespread presence in the mouth and more particularly in infected tonsils, it may readily be aspirated into the lungs under suitable conditions; there, in conjunction with other organisms, it may set up infection.

Of twenty-seven cases of abscess of the lung included in the present study, twenty-one were chronic, long-standing cases, and the material

was secured at or prior to operation. Of these twenty-one cases, a search for *B. melaninogenicum* was made in only seventeen, the other samples being studied before the presence of this organism was known; as a result the plates were discarded too soon to identify it. *B. melaninogenicum* was found in 94 per cent, or in sixteen of the seventeen recorded cases. In two of these cases, or in 9.5 per cent, the colonies of *B. melaninogenicum* on the plates constituted from 60 to 90 per cent of all the colonies present, and an exceedingly rapid breaking down of the hemoglobin took place (in less than forty-eight hours) with a concurrent production of an exceedingly foul odor, resembling that previously referred to. From one sample, or 5.9 per cent, between 20 and 30 per cent of all colonies growing were those of *B. melaninogenicum*. Five other samples, or 23.8 per cent, contained between 3 and 7 per cent of these organisms. Eight patients, or 38 per cent, had 2 per cent or less of the colonies, although numerically there were large numbers of the organisms present in the pus from most of these patients, and although from a casual inspection of the plates one might suppose them to be much more numerous. *B. melaninogenicum* was completely absent in only one case, or 5.9 per cent, even on repeated examination. The bacterial flora of this sample was quite different from that of any of the other samples studied, as may be seen by referring to case 2, table 1, which shows the bacteriologic observations in this sample.

In all of the samples of pus studied, there was a close relationship between the pus obtained from the patient and the bacterial flora in respect to *B. melaninogenicum*. This was particularly true in respect to the presence of granules. Of the samples of pus from typical chronic abscess of the lung in which granules were observed, *B. melaninogenicum* was found in all but one, as well as in many cases not included in this series. In the more putrid types of pus, in which the granules were often numerous, as compared with those found in less putrid types of pus, the numbers of *B. melaninogenicum* were always greatly increased. If only a few granules or none were present, there were only a few colonies of *B. melaninogenicum* found on culture. There was therefore a close relationship between the presence of these granules and the numbers of the black organisms present.

The odor given off from pus containing *B. melaninogenicum* is characteristic, and as the strength of the odor is apparently in direct proportion to the numbers of *B. melaninogenicum* present, an experienced worker may with considerable accuracy predict the absence or presence of the organism on this basis, together with the numbers to be expected. When grown on blood agar plates in symbiosis with fusiform bacilli, either alone or with streptococci, the organisms produce the same odor but in greater degree.

Results of Cultural Examination of Pus from Chronic Abscesses of the Lung

Case *	Sex	Odor of Pus	Granules in Pus	Spirochetes in Pus	Anaerobic Growth †										Aerobic Growth †										Comment
					Identified						Unidentified				Identified					Unidentified					
					B. Fusiformis	B. Melaninogenicus	S. Hemolyticus	S. Viridans	Nonhemolytic Streptococci	Other Organisms	Gram-Positive Nonhemolytic Diplococci	Gram-Negative Nonhemolytic Diplococci	Diphtheroids	Other Organisms	S. Hemolyticus	S. Viridans	Nonhemolytic Streptococci	S. Aureus	Pneumococci	Diphtheroids	M. Catarrhalis Group	Gram-Positive Nonhemolytic Diplococci	Gram-Negative Nonhemolytic Diplococci	Other Organisms	
1	M	Very foul	++++	— / ++	7%	5%	—	80%	..	±	..	5% / +	—	—	..	60%	..	+	..	..	..	..	..	+	Granules occurred as very small, evenly scattered, very soft masses; in column 5, the notation at the top indicates spirochetes from the liquid pus, the notation at the bottom, those found in the granules; no S. viridans found in granules; other organisms found were gram-negative spreaders of the proteus group; aerobic culture yielded a few colonies of M. tetragenous and a mucilaginous, gram-negative rod
2	M	Slight	++	+ / ++	1 to 2%	—	±	22%	..	..	+	12% / +	..	..	9%	22%	..	42%	20%	7%	..	..	±	..	
3	M	Slight	—	— / 0	4%	1 to 2%	—	+	..	..	..	++	..	..	+	±	..	..	++	..	..	..	++	..	
4	M	Putrid	+++	— / +	5%	1%	±	4%	..	..	45%	45%	..	..	..	79%	15%	..	..	..	5%	±	±	..	
5	M	Foul	+++	— / +	1%	1%	—	+	..	..	+	30%	..	..	..	40%	..	..	..	..	±	55%	±	..	
6	F	None	+++	— / 0	<1%	25 to 30%	—	60 to 75%	..	..	+	..	..	..	..	>99%	..	..	..	..	..	±	±	..	
7	M	Slight	+ bloody	— / +	1%	<1%	—	—	..	..	+	60 and 10%	..	..	..	60%	..	..	..	..	<1%	..	..	40%	Two types of gram-negative nonhemolytic diplococci were present; no gram-positive organisms grew; M. tetragenous was found in aerobic culture
8	F	None	++	— / —	3%	1%	+	—	..	..	+++	40% / ++++	..	..	..	..	..	..	90%	..	+	..	..	10%	Sarcina lutea was found in aerobic culture; vibrios present in very small numbers
9	M	Slight	—	+ / 0	1 to 2%	7%	—	5 to 10%	..	..	..	40% / +++	..	..	++++ / 90%	..	..	..	10%	..	±	..	..	..	

10	M	Slight	±	— +++	1%	90%	—	+	<10%	..	..	±	..	..	++++	35% ++++	..	..	..	..	+	+	+	..	B. fusiformis very numerous microscopically in anaerobic culture
11	F	Foul	+++	+ ++++	1%	+++ 60%	+	±	..	..	..	+	..	..	25 and 65%	..	..	..	..	..	9%	..	1%	..	Black granules present; the spirochetes and gram-negative cocci constituted 99 per cent of the microscopic flora; two types of hemolytic streptococci were shown in aerobic culture, together constituting 90 per cent of the flora
12	M	Very foul	+++	± ++++	1%	2%	—	80%	..	..	+	±	..	..	..	25%	..	..	..	..	<1%	..	75%	..	
13	M	Slight	—	+ 0	1%	1%	+++	+++	..	+++	..	..	...	..	>98%	1%	..	..	..	..	..	..	..	+	M. tetragenous was found in both anaerobic and aerobic cultures
14	M	Slight	++	— ++	50%	3 to 4%	++	4%	+	..	+	8% ++	..	..	++	75% ++++	..	..	..	..	..	..	..	..	
15	M	Slight	+	— 0	60%	5 to 7%	±	+	30%	..	..	..	..	..	+	+	75 to 95%	..	..	..	..	..	+	..	
16	M	Slight	—	+ 0	25%	0	—	70%	..	..	+	+	..	..	..	80% ++++	..	..	..	..	+	..	..	..	
17	M	Very foul	++++	± +	65%	0	7%	7%	..	..	+	++	..	..	+	40% +++	..	..	..	..	..	..	+++	..	
18	M	None	—	— 0	7%	0	6%	+	..	..	+	+	..	..	+++	28% +++	..	..	..	..	..	..	+++	..	
19	M	Slight	+	— +	4%	7%	7%	+	..	..	+	+	..	..	70% +++	+	..	..	..	..	..	..	+++	..	
20	M	Foul	—	— 0	6%	0	—	50%	..	..	+	+	..	..	..	100% ++++	..	..	..	..	..	..	..	..	
21	M	Very foul	++++	+ ++	±	1 to 2%	—	—	..	±	..	..	..	..	+	+	..	<1%	..	..	..	..	..	..	S. albus was found in anaerobic culture
22	F	Foul	0	+ 0	±	1%	50%	<1%	..	+	..	+	..	..	..	..	..	..	..	..	..	..	..	..	Colonies of B. melaninogenicum contained red pigment; S. albus and S. aureus were found in equal numbers in anaerobic culture
23	M	Slight	0	— 0	—	+	—	—	..	..	..	..	99%	..	—	—	..	..	..	..	..	>99%	..	..	
24	F	Foul	+	— +	40%	0	50%	—	..	..	..	..	+	5 to 10%	—	—	—	—	—	—	—	—	—	—	Weakly hemolytic gram-positive diplococci were found in anaerobic culture
25	M	Slight	0	—	—	±	—	—	..	+	++++	..	..	..	..	..	..	..	..	..	+	..	..	+	No spirochetes were seen microscopically; B. pyocyaneus was shown in anaerobic and aerobic cultures
26	F	Slight	0	—	±	0	99%	—	..	..	..	..	..	±	..	++++	..	..	..	..	..	..	+	+	..	
27	F	Slight	0	—	+	0	80 to 90%	—	..	..	..	..	..	..	..	+	..	..	..	..	..	..	..	..	..	

* Cases 1 to 21, inclusive, are those in which no operation had been performed; cases 22 to 27, inclusive, those in which an operation had been performed and which were in the process of healing.

† The amount as well as the percentage of growth of the various organisms (when this was possible to obtain and check by repeated culture) is indicated. The notation — indicates the absence of the organisms; ±, occurring rarely, much less than 1 per cent; +, fairly good growth; ++, a good growth; +++, a very heavy growth; ++++, the majority of the growth is of this type, and the colonies are profuse.

The mere presence or absence of an organism in a pathologic lesion cannot, of course, be taken as a criterion as to its etiologic significance in connection with that lesion, and while there are no exact experimental data as to the relationship between *B. melaninogenicum* and abscesses of the lung, certain factors would seem to show that it may be of great importance in this disease. The organism may be present, of course, only as a secondary invader or saprophyte and may grow more readily in the older lesions simply because of better conditions of nutrition. Experimental evidence is against the idea of any one organism causing these lesions, but rather points to several organisms growing in intimate symbiosis with each other as giving rise to the condition; one organism, enabled to grow by means of the withdrawal and continual exclusion of oxygen by the other bacteria, penetrating into healthy tissue, injuring it so that other organisms of the group may follow and injure it still further, allowing those organisms which live on necrotic or liquefied tissue to complete the process. The most frequently found and probably the chief organisms concerned in this process are *B. melaninogenicum*, fusiform bacilli, spirochetes and streptococci, especially of the viridans type. In pure culture, *B. melaninogenicum* so far has proved to be devoid of pathogenic properties, but in symbiotic growth its numbers increase rapidly in experimental lesions, coincident with a marked change in the character of the pus from the light yellow pus seen in early lesions, which is largely devoid of odor, to the chocolate-brown, foul smelling pus seen in the advanced cases in human beings. In the series of experiments by Allen [1] on the experimental production of abscesses of the lung in dogs, pus from one of the patients studied in this series (case 21) was secured at operation, kept at 37 C., and introduced into the bronchus of a dog under ether anesthesia, following which the bronchus was ligated. After twenty-six days the dog, in a dying condition, was chloroformed; autopsy disclosed an extensive abscess in which was found a large amount of foul smelling, dark brown pus, which physically resembled that originally introduced, except that it was slightly more liquid, and which had a strong odor of *B. melaninogenicum*. A large number of cheesy granules was found in the pus. However, while only about 1 per cent of colonies of *B. melaninogenicum* was found in the original pus, in the pus from the dog the anaerobic growth showed approximately 50 per cent of the organisms from one sample and almost 100 per cent from another to be *B. melaninogenicum*, no sample showing less than 50 per cent of the organisms. Aerobically, practically 100 per cent of the colonies growing were of a small, nonhemolytic streptococcus. The soft, yellowish, cheesy granules were found in large numbers, and varied in size from a fraction of a millime-

ter to several millimeters in diameter. On staining, these granules were seen to teem with spirochetes, and with considerable numbers of fusiform bacilli. Few spirochetes were found in the liquid pus. The hemoglobin in the blood agar plates was destroyed rapidly, the plates all becoming decolorized in less than four days, coincident with the formation of an intense black pigment in the colonies of *B. melaninogenicum*. Numerically, the fusiform bacilli were present in considerable numbers, but relatively there was only a small percentage of such colonies present. The same gram-positive streptococcus seen in the aerobic cultures appeared in the anaerobic cultures, but in much smaller numbers.

It may be seen that in this experimental abscess, the numbers of *B. melaninogenicum* increased tremendously. The other organisms, while still numerically present in large numbers, were greatly decreased in percentage at the expense of *B. melaninogenicum*. Results similar to those secured in this experiment were obtained a second time, using another patient (case 19) and another experimental animal.

While the results of only one or two experiments can at best be merely indicative, the evidence is at least suggestive that *B. melaninogenicum* may and probably does play more than a passive rôle in the production of abscesses of the lung. It should be repeated, however, that it is unlikely that any one organism may be incriminated as the etiologic agent, but rather that several organisms, as previously mentioned, act symbiotically to bring about this condition. The spirochetes and fusiform bacilli are the outposts of the advancing infection, producing an injury which is carried on to completion by streptococci and *B. melaninogenicum*. The streptococci as well as other aerobic cocci are of aid in this process not only because of their inherent pathogenic powers, but also because of their ability to maintain anaerobic conditions, an essential for the other organisms. To the presence of *B. melaninogenicum* must also be attributed much of the disagreeable nature of the infection, because of the foul nature of the pus so produced.

Of the six cases studied in which operation was performed, the presence of *B. melaninogenicum* was recorded in only three, and here only in small numbers. However, since the pus from these patients was obtained by swabbing from the exterior through the wound fissure, there was less chance for an anaerobic flora than in the cases in which no operation was performed. Even with deep swabbing, however, few colonies of *B. melaninogenicum* were ever found. There is a definite decrease in these organisms following operation; this decrease is both quantitative and, more especially, qualitative, there being a great increase in aerobes at the expense of the anaerobes.

BACILLUS FUSIFORMIS

Of the twenty-one cases studied in which no operation was performed, *B. fusiformis* was found in twenty cases, or 95 per cent, by microscopic examination. By means of cultural tests, the organisms were found in twenty-one, or 100 per cent, of the cases. It is of interest to note that in several cases microscopic examination showed the presence of myriads of gram-negative organisms, with a few scattered gram-positive organisms of the same type, which were at first diagnosed as typical *B. fusiformis,* but which on culture proved to be gram-positive diphtheroids, which have the same size and shape as *B. fusiformis.* Even an experienced observer, therefore, finds it unsafe to trust mere microscopic examination in establishing the presence or numbers of *B. fusiformis* in the lesions. In the cases mentioned, actually only a few colonies of *B. fusiformis* developed, although large numbers of the diphtheroids were found. Cases were also encountered in which a large number of organisms which appeared to be vibrios was found, but which on culture proved to be *B. fusiformis.*

In only three, or 14.3 per cent, of these twenty-one cases were the colonies of *B. fusiformis* present in a concentration of from 50 to 60 per cent or in the majority. In one case, or 4.75 per cent, 25 per cent of the organisms cultivated were *B. fusiformis.* In four cases, or 19 per cent, between 5 and 7 per cent of the colonies were those of *B. fusiformis.* In the other cases, numbering thirteen, or 62 per cent, from 1 to 4 per cent of the colonies were those of *B. fusiformis.* As in the case of *B. melaninogenicum,* in enumerating these organisms one should actually count the various colonies found in order to arrive at any accurate estimate as to the percentage of various types of bacteria present, as it is easy to overestimate the percentage of an organism which has so characteristic and striking a colony as *B. fusiformis.*

Several different types of *B. fusiformis* were found in these lesions, the most numerous of which were the types I and II previously described by me.[8] Type IV is frequently seen microscopically in small numbers in the pus, but due to difficulties in cultivation, it is very hard to grow and count it in numbers corresponding to those present in the lesion.

In two of the six cases in which operation was performed, no fusiform bacilli were found by microscopic examination or by culture. One case, microscopically negative, was positive by culture. One case, weakly positive microscopically, was weakly positive by culture, colonies of *B. fusiformis* constituting about 0.1 per cent of the total flora. Two

8. Varney, Philip L.: The Serological Classification of Fusiform Bacilli, J. Bact. **13**:275, 1927.

cases that were weakly positive microscopically revealed on cultivation considerable numbers of fusiform bacilli. Of the six cases in which operation was performed, therefore, fusiform bacilli were found in four, and were absent in two. As in the case of *B. melaninogenicum*, the number of these organisms in patients undergoing operation was found to be greatly decreased. In general, the microscopic method for the detection of fusiform bacilli has proved to be less reliable and sensitive than the cultural test, contrary to general opinion.

SPIROCHETES

In only one of the twenty-one cases in which operation was performed was there apparently a greater number of spirochetes than of other organisms in the microscopic preparations. Since the relative numbers of these organisms can be determined only by comparatively unreliable microscopic methods, the numbers actually present cannot be checked by cultural controls. In two additional cases spirochetes were found in large numbers in the lesions, and in three cases in fairly large numbers. In eight cases, or 38 per cent, spirochetes were present in numbers corresponding to between one and five per field. In six samples no spirochetes were found. Of the twenty-one cases, therefore, spirochetes were present in 71.4 per cent and absent in 28.6 per cent.

Of the cases in which operation was performed, spirochetes were found in only two, and here were present in small numbers; one of these cases showed only one spirochete to each two fields examined, and the other, approximately one or two organisms per field. The other four cases were entirely negative even after long search. It is difficult, however, to search for spirochetes in pus from an organizing wound, as the large amount of fibrin and cellular débris makes it almost impossible to stain the organisms and not stain the background to such an extent that the organisms are concealed. It may safely be said, however, that there is an almost total absence of spirochetes in the patients operated on.

STREPTOCOCCI

In only three of the twenty-one cases in which operation was not performed were colonies of *Streptococcus hemolyticus* found in numbers greater than a few per plate under anaerobic cultivation; in these cases they constituted from 6 to 7 per cent of the total flora. In practically all the cases a few colonies were found on the plates, but in too small a number to be recorded.

In five of the twenty-one cases, *Streptococcus viridans* was found, in anaerobic cultures, to constitute a majority of the organisms present, varying from 50 to over 80 per cent of the total number of colonies

present. In five other cases they were found in smaller numbers, and in eleven remaining cases they were found in very small numbers.

In the aerobic cultures the numbers of streptococci were greatly increased over those cultured from the same material but incubated under anaerobic conditions. In four cases, *S. hemolyticus* constituted a majority of the flora, occurring in as great a concentration as from 90 to 98 per cent. In three other cases they were found in large numbers, varying from 10 to 20 per cent, and in five other cases they were found in only small numbers, constituting from 1 to 5 per cent of the flora.

Under aerobic conditions, *S. viridans* was frequently found in large numbers, as well as constituting a high percentage of the total flora present; colonies of this organism constituted a majority of the flora in seven cases, the percentage varying from 60 to 100 per cent. The liquid portions of the pus ordinarily contained larger numbers of the streptococci than the granules. In six cases, from 22 to 40 per cent of the colonies growing were those of *S. viridans.* In four cases they were found in small numbers varying from 1 to 5 per cent of the total flora, and in the remaining cases, they constituted only a negligible part of the flora, only an occasional colony being found out of thousands present. Thus, of twenty-one cases in which there had been no previous treatment, eighteen, or 85.7 per cent, were positive for *S. viridans.*

Of the six cases studied in which treatment was given, four showed a high percentage of *S. hemolyticus,* the percentage varying from 50 to 99, under anaerobic conditions. Under aerobic cultivation, only one of these cases showed a majority of this organism present, and in only two of the six cases were colonies of *S. hemolyticus* encountered. In all of the treated patients there was a sharp decrease in the number of organisms of all kinds, with an increase in percentage of *S. hemolyticus* over that encountered in the untreated patients. In contrast to the apparent increase in the numbers of *S. hemolyticus* there was a total lack of colonies of *S. viridans* on any of the anaerobic plates, and in only one of the cases was this organism found on the aerobic plates.

Small gram-negative and gram-positive cocci were encountered in many of the samples examined, the gram-negative organisms outnumbering the gram-positive forms. These organisms were of several different species, and apparently had no constant relationship to the material under study.

In the table, no attempt was made to include the many organisms that were found, chiefly in small numbers, in only one or two of the samples studied, and that were probably saprophytic or derived from accidental contaminations from the sputum.

In only two cases were pneumococci found in large numbers. In one case they constituted 20 per cent of the flora, and in another they were present in a concentration of 95 per cent under aerobic conditions. In the first case, the pneumococci were accompanied by hemolytic *Staphylococcus aureus* which constituted 42 per cent of the flora. Staphylococci were rarely encountered in this series of cases.

CONCLUSIONS

Twenty-seven cases of chronic abscesses of the lung were studied in respect to their bacterial flora, twenty-one of which were from previously untreated patients. Streptococci, fusiform bacilli, *B. melaninogenicum* and spirochetes were the organisms most commonly encountered in the material from the lesions of the untreated patients; *S. viridans* was found more frequently than *S. hemolyticus*. In the treated patients, the fusiform bacilli, spirochetes and *B. melaninogenicum* greatly decreased in number or disappeared altogether, coincident with a relative increase of *S. hemolyticus*. The bacterial flora of material from chronic abscesses of the lung showed a remarkable similarity to that from infected tonsils, cervical abscesses and diseased teeth and mucous membranes.

7. EARLY CARCINOMA OF THE LUNG*

S. H. GRAY, M.D.
AND
J. CORDONNIER, M.D.
ST. LOUIS

It is generally recognized that considerable light will be thrown on the histogenesis of cancer, especially that of internal organs, through the study of early cases, and through the study of inflammatory or other irritative processes that may produce excessive epithelial proliferation. Much that would increase the knowledge of carcinoma of the lung was hoped for after the influenza epidemic of 1919 and 1920. One is struck, however, by the fact that although innumerable pathologic reports have been published on influenza, only a few mention excessive regeneration of the epithelium of the lung that may possibly be interpreted as significant in the etiology of carcinoma. Askanazy,[1] Glaus and Fritsche,[2] Winternitz and others,[3] Wolbach and Frothingham[4] and Schmidtmann[5] have described epithelial proliferation that appears to begin in the bronchus and may invade the alveoli and in some instances the peribronchiolar tissue. Most of the cases described were found in people who died soon after the onset of the disease. In his recent review of this subject, Weller[6] stated that not influenza itself but "the sequelae of influenza, so far as they bring about bronchiectasis or chronic fibroid pneumonia are of importance" as precursors of carcinoma. The latter pathologic changes may play a rôle irrespective of the organism or mechanism that produces them. As early as 1876, Friedländer[7] discussed this relation between certain pathologic conditions of the lung and carcinoma.

Chemical and physical irritants have also been emphasized as important factors in human and experimental carcinoma of the lung. This phase of the problem also is reviewed by Weller.

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* From the Department of Pathology, Washington University School of Medicine and Barnes Hospital.

1. Askanazy, M.: Cor.-Bl. f. schweiz. Ärzte **49**:465, 1919.

2. Glaus, A., and Fritsche: Cor.-Bl. f. schweiz. Ärzte **49**:72, 1919.

3. Winternitz, M. C.; Wason, I. M., and McNamara, F. P.: The Pathology of Influenza, New Haven, Yale University Press, 1920, pp. 61.

4. Wolbach, S. B., and Frothingham, C.: Influenza Epidemic at Camp Devens in 1918, Arch. Int. Med. **32**:571 (Oct.) 1923.

5. Schmidtmann, M.: Virchows Arch. f. path. Anat. **228**:44, 1920.

6. Weller, C. V.: Pathology of Primary Carcinoma of Lung, Arch. Path. **7**: 478 (March) 1929.

7. Friedländer, C.: Virchows Arch. f. path. Anat. **68**:325, 1876.

The histologic picture of the lung in the case that we are about to describe has a few points in common with that recorded in some of the conditions just mentioned. However, the impossibility of finding any clinical relationship between the two and the fact that the changes in this lung are so much more advanced than those described in the other conditions leave us with no doubt but that we are dealing with an early carcinoma of the lung and not with a benign epithelial hyperplasia. Our study was brought about through an accidental observation in the routine microscopic study of a case that had given no clinical or gross anatomic evidence of any unusual pulmonary change. The relatively slight and

Fig. 1.—Papillomatous hyperplasia of the epithelium of the ductus alveolaris. Hematoxylin and eosin; × 61.

early involvement offers valuable information concerning the histogenesis of multiple carcinoma of the lung.

E. N., a colored woman, aged 78, entered the surgical service at Barnes Hospital suffering from a fracture of the right femur, sustained in a fall from a porch. She was mentally clear and alert. During her stay of one month in the hospital, there was ample time for obtaining a history. She said that she had never been sick, except for some vague diseases of childhood. We can be reasonably sure that she had had no illness for ten years at least. Except for the condition of the lung, there was nothing of interest in the physical or postmortem examination.

Grossly, the lungs were pale pinkish gray, mottled with black. In the right upper lobe the pleura was somewhat thickened, and on section there appeared to be an increase in connective tissue and coal pigment. At the apex, there was a minute calcified nodule. Because the changes were apparently slight, the whole lungs were not preserved.

After an early carcinoma had been discovered microscopically, all the blocks of tissue that had been preserved in solution of formaldehyde and alcohol were cut serially. The sections of lung tissue showed a moderate, fairly diffuse fibrosis (figs. 1 and 5), with small amounts of carbon particles embedded in the meshes of the connective tissue. In no place did the fibrosis suggest healed tubercles, but this did not absolutely rule out an old tuberclous process. The smaller bronchi were dilated, and their walls only slightly infiltrated with lymphocytes. The bronchioles and ducti alveolares were markedly dilated and irregular, with hypertrophic epithelium. Small collections of lymphocytes and occasional plasma cells were found here and there in the lung. Many of the alveoli were emphysematous. Three small cancer masses were found, which were distinct and separate from one another.

Fig. 2.—High power magnification of figure 1, showing the appearance of the cells. Hematoxylin and eosin; × 244.

Figures 1, 2, 3 and 4 are photographs from one of the tiny cancer nodules. Figure 1 shows a marked hyperplasia, papillomatous in appearance, of a ductus alveolaris. To the left, one can see the transition between the unusually tall one-celled epithelial lining of the ductus alveolaris and the many-celled neoplastic tissue; to the right the tumor is seen in communication with emphysematous alveoli. Figure 3 gives a higher power photograph of this transition. In the lower left corner of figure 1 are a dilated terminal bronchiole and a ductus alveolaris. In the right center are two ducti alveolares in communication with alveoli. A little above the center, the tumor extends into and lines an alveolus. The tumor cells can be studied better in figure 2. They are of medium size, with light staining nuclei; nearer the base they are elongated, while at the surface the cells assume a polygonal shape.

Invasion of the lymphatics evidently occurs early; for this tumor, which is less than a millimeter at its widest, shows definite invasion of the lymphatics. Figure 4

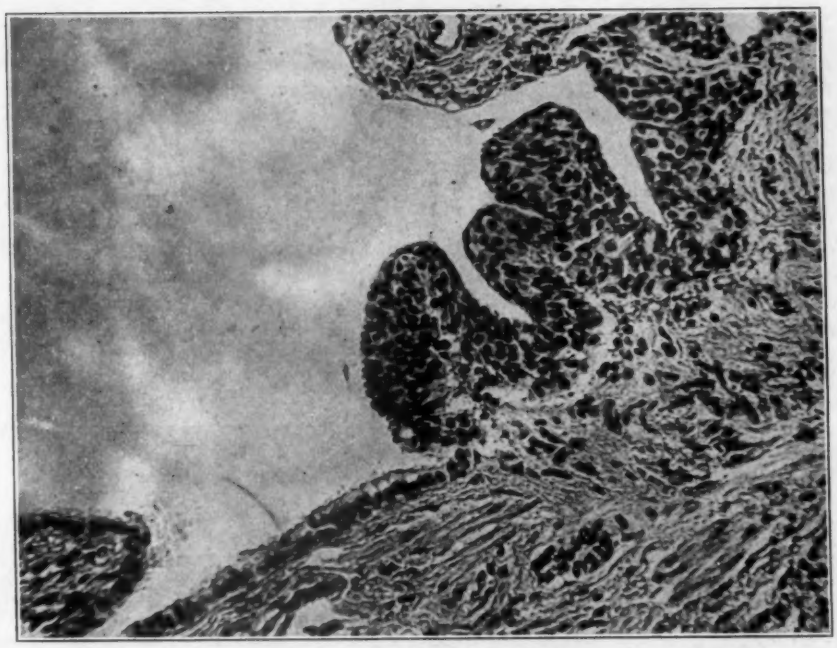

Fig. 3.—Transition between hypertrophic epithelium of the ductus alveolaris and the papillomatous new growth. Hematoxylin and eosin; × 269.

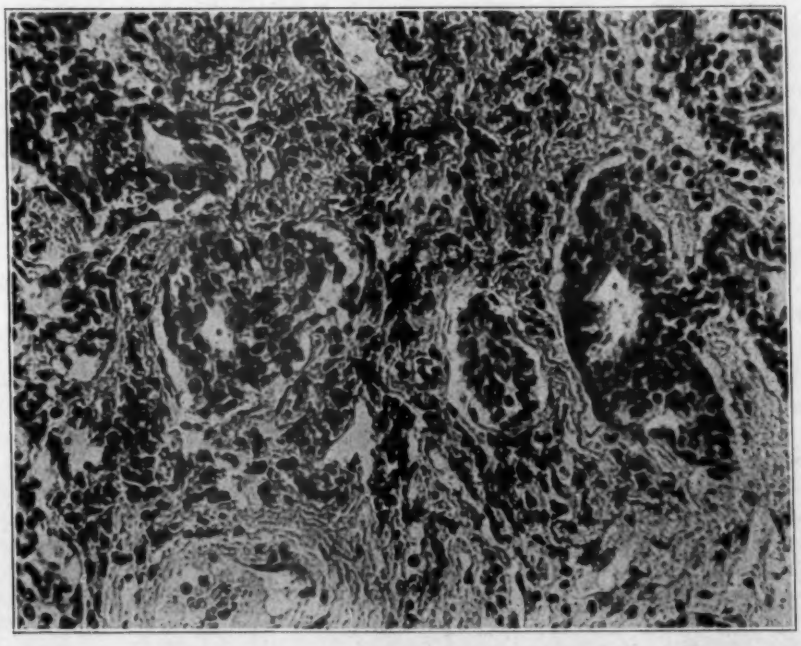

Fig. 4.—Another part of the same tumor, showing invasion of the lymphatics. Hematoxylin and eosin; × 294.

is a photomicrograph of another area from the same tumor nodule showing small nests of cells in lymphatics. The cells show some irregularity in size and in shape, with nuclei which stain somewhat deeper than those previously described.

Figures 5, 6 and 7 picture the second tiny tumor. Figure 5 is a low power photomicrograph of the entire tumor mass, which consists of small islands of tissue lying in lymphatics. Figure 6, which is a high power photograph of the right upper corner of figure 5, is the only area in which there is a possible connection with an epithelial surface. The layer of cells along the right upper margin of the tissue might be taken for epithelium lining a ductus alveolaris, especially since in figure 5 the tissue lies at the opening of a distended alveolus. Unfortunately, all the tumor had been cut away when the routine sections were made so that serial sections of what remained of the block gave no further information. Figure 7 is a high power view of one group of cancer cells in a lymphatic, in

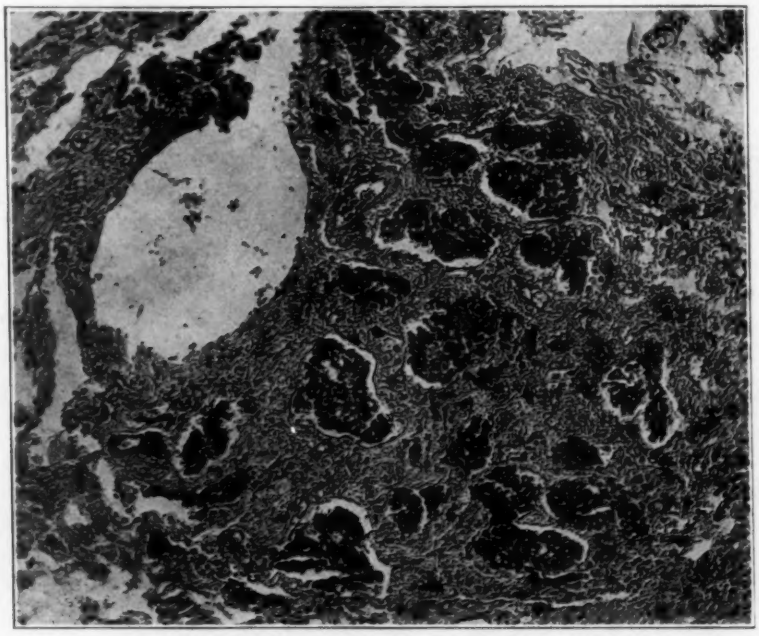

Fig. 5.—Photomicrograph of second small neoplasm. Most of the cancer is seen in lymphatics. Hematoxylin and eosin; × 111.

which one may see two questionable mitotic figures, and some variation in size, shape and staining quality of the cells.

Although the third nodule was sectioned completely, no definite primary site could be detected unless figure 8 were interpreted as such. However, this is probably cancer tissue growing into an alveolus. In figures 9 and 10 taken from the third nodule, differentiation of the invading tumor is apparent; in figure 9, a solid sheet of cells is seen in one lymphatic, and a pseudo-alveolar arrangement in another; in figure 10, flat elongated cells are found in a lymphatic. The blood vessels were not invaded by the cancer.

The other organs did not show any change which might be connected with the process found in the lung; no evidence of carcinoma was found in any other part of the body.

COMMENT

One of the most interesting features of this early neoplasm is the origin of cancer of the lung from the ductus alveolaris. The bronchi and bronchial glands have been accepted as definite sites of origin for cancer. The alveolar epithelium has been a doubtful source, although Ewing [8] has accepted it in his classification. We could find no reference to the ductus alveolaris as a primary site. In view of this uncertain alveolar origin of cancer, especially since Fried [9] and Rose [10] in their recent work have again seriously questioned an epithelial lining of the

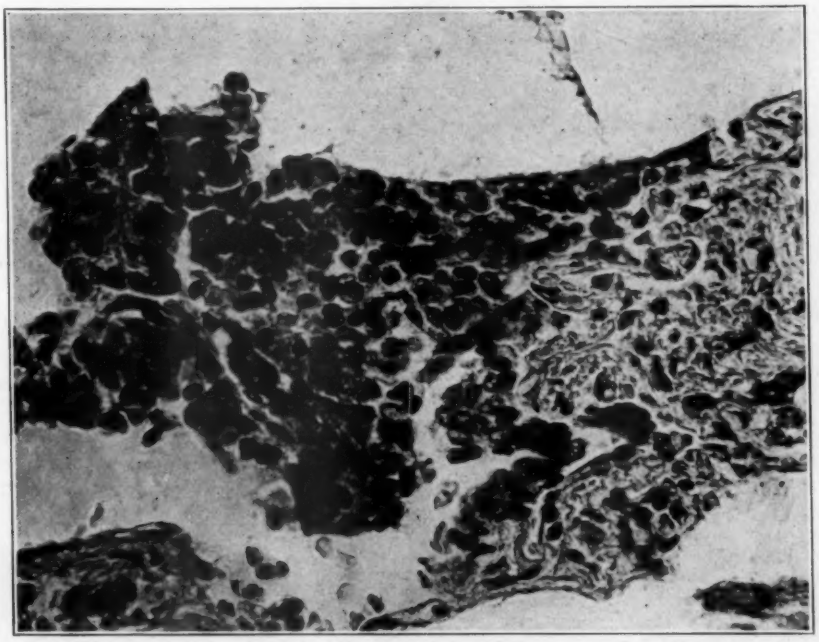

Fig. 6.—Possible point of origin of second tumor from a ductus alveolaris. Hematoxylin and eosin; × 524.

alveoli, we think that it would be of value to restudy the cancers to trace a possible origin from the ductus alveolaris. This is especially true of the multiple nodular carcinomas, which the case that is being presented resembles.

If we had been more fortunate in the amount of tissue that had been preserved, we could have answered definitely the question as to the

8. Ewing, J.: Neoplastic Diseases, Philadelphia, W. B. Saunders Company, 1928.

9. Fried, B. M.: Origin of Histiocytes in Lungs, Arch. Path. **3**:751 (May) 1927.

10. Rose, S. B.: Finer Stricture of the Lung, Arch. Path. **6**:38 (July) 1928.

multicentric origin of pulmonary carcinoma. There can be no doubt about the primary site in tumor 1. Although we think that figure 6 shows a probable primary site in tumor 2, we cannot say so with certainty. Tumor 3 is metastatic. The studies that have been made on this type of carcinoma of the lung favor a multicentric origin. Multiple cancers of the lung, however, may be produced in a way other than from multiple primary sites. The early invasion of lymphatics sends numerous small nests of cells to other parts of the lung. In a lung in which there has been an old inflammatory lesion that has resulted in scarring, a large number of the lymphatics are blocked. The cancer metastases thus can-

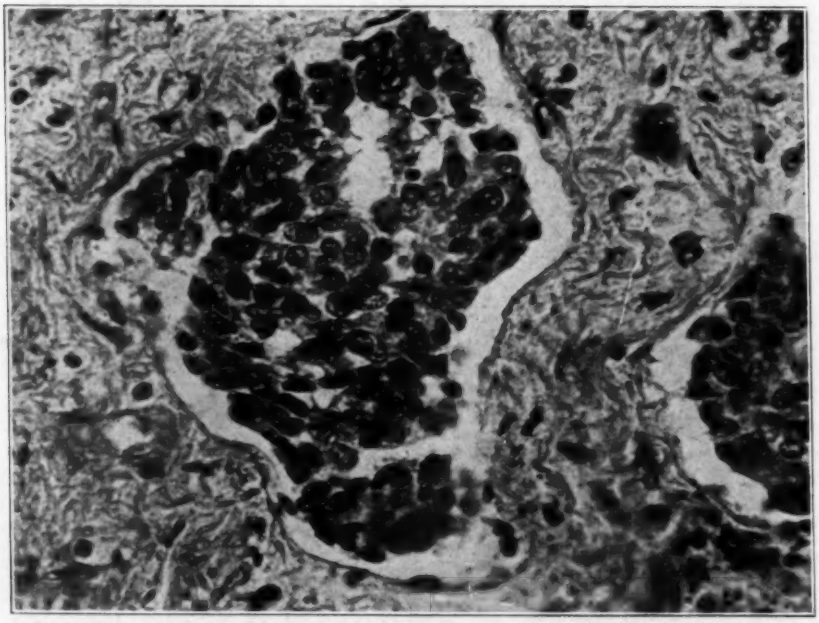

Fig. 7.—A higher power magnification of figure 5 of the cancer tissue in a lymphatic. Hematoxylin and eosin; × 536.

not proceed beyond the scar and grow in the region of this fibrosis. The neoplastic tissue can travel by retrograde metastases to other parts of the lung and there set up small cancer nodules. In the three small tumors, there was little difference in their size, even though one of them is probably a metastasis, thus denoting early invasion of the lymphatics and dissemination to other parts of the lung. It is even possible for the tumor metastases to get to the other lung by way of retrograde growth from tracheobronchial lymph nodes where the lymphatics of both lungs meet. This may be a more plausible way, if the tracheobronchial lymph nodes have been the site of a chronic inflammatory process. Two sources must therefore be considered to account for multiple nodular carcinomas of the lung: multicentric origins and early metastases.

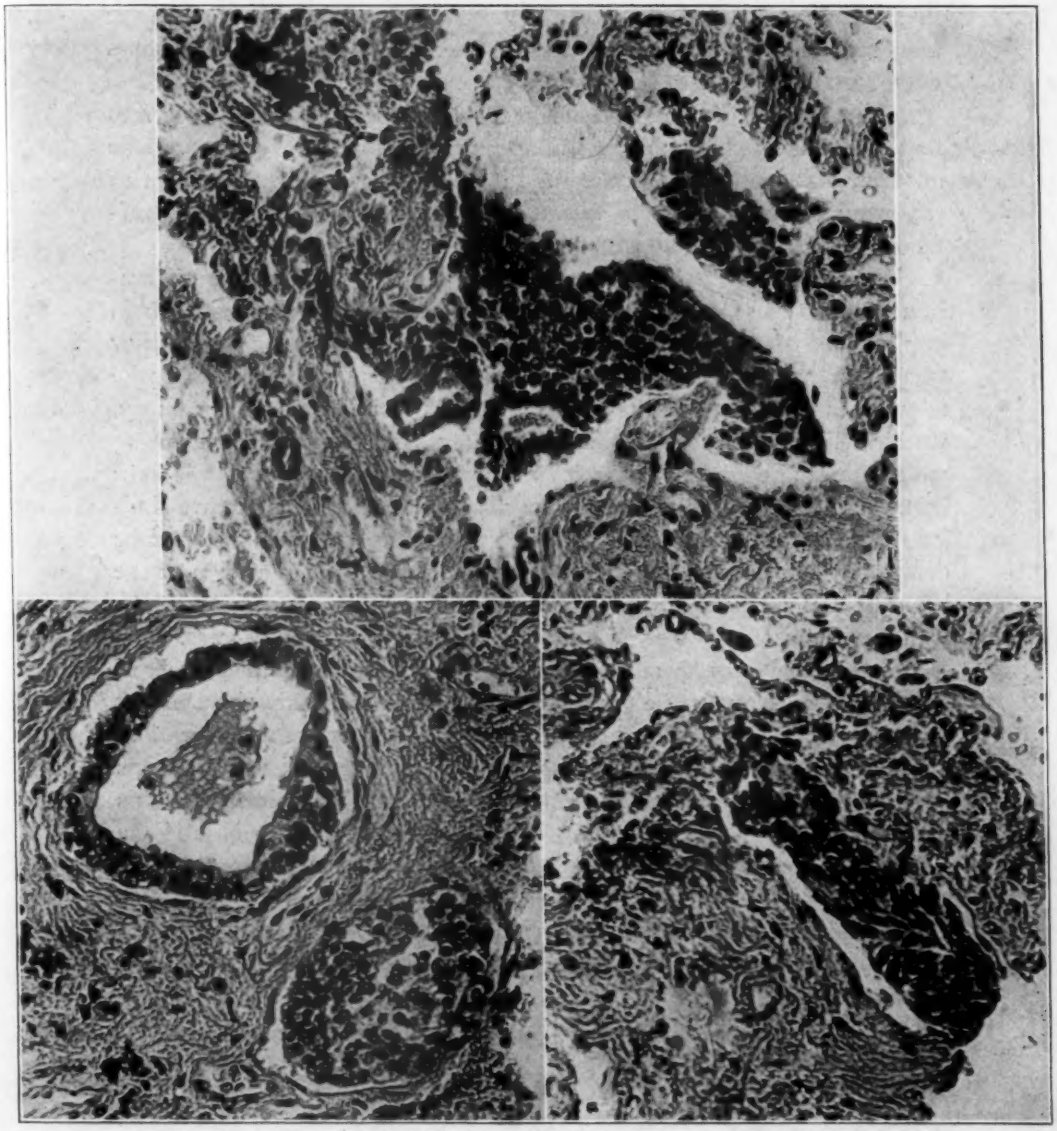

Fig. 8.—Areas from the third tumor nodule, showing invasion of alveoli and lymphatics. Notice the variety of forms the tumor may assume. Hematoxylin and eosin; × 300.

Tumors 2 and 3 appear to be the most actively growing. The invasion of the lymphatics is extensive. The nuclei stain deeply, and the cells vary in size and in shape. Figure 8 shows the marked differences in appearance that cancer tissue may assume at an early stage, when the new growth is as yet microscopic in size. Few questionable mitoses were seen in any of the sections.

The question of the relationship of this process to other processes that produce epithelial proliferation may be briefly discussed. The experimentally produced proliferation of the lung parenchyma such as that produced by Winternitz, Smith and McNamara [11] by tracheal insufflation obviously plays no rôle in this case.

We have mentioned the reported occurrences of epithelial proliferation that have been observed in influenza, with which the condition in our case may be confused. No history of influenza was obtained, nor was there any history of infection of the lungs, although, to make allowances for the age of the patient and the possibility of poor memory, we have limited ourselves arbitrarily to ten years as the period during which we can be reasonably sure that there was no infection. We have been unable to find the report of any case with a histologic picture similar to the one described in which any relationship to influenza could be determined. The presence of connective tissue and the dilatation of the bronchioles may denote a previous inflammatory or irritative process; still, we have no means of determining the nature of that process.

At Barnes Hospital, although many postmortem examinations have been performed on people who have had influenza, nothing resembling this change in the lung has been found. In a personal communication, Dr. MacCallum stated that he has had a similar experience at Johns Hopkins Hospital. It would be difficult to imagine the existence of this lesion for a period of many years, as one would have to suppose if the patient had had influenza at some earlier period. Furthermore, if there had been a history of influenza, the inclination would still be great to look on this process as an early carcinoma, especially since one of these tumors in serial sections showed no relationship to an epithelial surface, and also because of the extensive invasion of the lymphatics and the marked differentiation of the epithelial nests.

CONCLUSIONS

1. An early primary carcinoma of the lung is described.
2. The epithelium of the ductus alveolaris is found to be the primary site.
3. Evidence is presented to show that multiple nodular carcinomas of the lung may arise from both multiple origins and early metastases.

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11. Winternitz, M. C.; Smith, G. H., and McNamara, F. P.: J. Exper. Med. **32**:205, 1920.

8. CONSEQUENCES OF VARIATIONS IN MEDIASTINAL PRESSURE; MEDIASTINAL AND SUBCUTANEOUS EMPHYSEMA*

HARRY C. BALLON, M.D.
AND
BYRON F. FRANCIS, M.D.
ST. LOUIS

The following experiences and observations concern the effect of variations in mediastinal pressure in the experimental animal. Particular attention has been paid to some of the consequences of mediastinal emphysema.

We use the term "increased mediastinal pressure," as did Jehn and Nissen,[1] in the same sense as "increased intracranial pressure."

Irrespective of the mechanism, any serious encroachment on the mediastinum must of necessity produce changes which are either local or general. Such changes may vary and may be dependent on the normal arrangement of the anatomic structures in the region concerned and their resistance to stresses and strains. It is certain that in a closed thorax one structure cannot expand to any great extent except at the expense of another. Air can, of course, escape into the subcutaneous tissues through the jugulum or dissect along fascial planes.

Graham [2] has shown that the presence of a liquid, gas or tumor in the pleural space may disturb the intrapleural pressures. Although all of these will exercise pressure on the lung, each operates in a slightly different manner, liquids acting in accordance with the laws of hydrostatic pressure, gases in the absence of adhesions exerting an equal pressure throughout, and tumors exerting their chief pressure wherever they happen to be located. Similar substances occupying the mediastinum act in practically the same way. Graham [3] has also shown that in unilateral open pneumothorax the important matter is the amount of air which enters through the opening at each inspiration and the ability of the individual to compensate for the encroachment on his respiratory

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*From the Department of Surgery, Washington University and Barnes Hospital.

1. Jehn, W., and Nissen, R.: Pathologie und Klinik des Mediastinalemphysems, Deutsche Ztschr. f. Chir. **206**:221, 1927.

2. Graham, E. A.: The Importance of the Vital Capacity in Thoracic Surgery, J. A. M. A. **75**:992 (Oct. 9) 1920.

3. Graham, E. A.: Alterations of Intrapleural Pressure and Their Significance, Medicine **3**:417, 1924; A Reconsideration of the Question of the Effects of an Open Pneumothorax, Arch. Surg. **8**:345 (Jan.) 1924.

surface which is caused by the open pneumothorax. The same may be said of mediastinal emphysema with the exception that the important factor in this case is the amount of air retained in the mediastinum. The retained air is inspired air which cannot be expired. The position and size of the opening which is allowing the air to escape into the mediastinum is therefore of some import. Granted that air does not escape into the subcutaneous tissue or that a pneumothorax does not develop, the acting mechanism will then be quite similar to that of an uncomplicated valvular pneumothorax. Also of considerable importance, therefore, is the pathway which the escaped air takes.

The normal pressure on the mediastinal structures has been roughly expressed as being that of atmospheric pressure minus the pressure exerted during the normal retraction of the lung (Assmann [4]).

We have tried in a general way to consider the consequences of variations in mediastinal pressure from the standpoint of those expressive of either inspiratory or expiratory (dyspnea) distress. Attention has been paid to the effects of variations in mediastinal pressure on the great vessels. For it soon became evident that they may be readily compressed and the respiratory passages remain free as in cases of the so-called status thymico-lymphaticus. Anatomically considered, it is much easier for compression of the large blood vessels to occur than of the trachea or bronchi. Cyanosis and dyspnea were more often observed to be expressions of compression of the former than of the latter. Pulmonary compression and mechanically impaired heart action are considerations which demand considerable attention. For the resultant emphysema which may be patchy, unilateral hypoventilation of one lung, hyperventilation of the other and the stagnation of blood in the lungs which in some measure is also due to hindered heart action may soon apparently lead to edema of the lungs and to the development of fluid in the pericardial cavity. The vital capacity can thus be quickly reduced.

Edema of the tracheobronchial mucous membrane is, of course, another consideration. Such factors as carbon dioxide tension, hydrogen ion concentration and vagus regulation have received but scant attention. It is, however, appreciated that they must play a significant rôle in the experiments here recorded.

We have recorded some of the variations in the arterial, venous and intrapleural pressures which result from changes in the size, shape and contour of the anterior and posterior mediastina. Changes noted in the respirations were also recorded.

The results of our experimentation perhaps permit us to make some few clinical analogies throughout our discourse.

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4. Assmann, H.: Klinische Roentgen diagnostik der inneren Erkrankungen, Leipzig, F. C. W. Vogel, 1929.

HISTOLOGY OF THE MEDIASTINUM

The finer histologic structure of the mediastinum has recently received consideration at the hands of Seifert.[5] He has shown definitely that there is a histologic basis for the reason why the mediastina of various animals react differently to artificial pneumothorax. He noted that the histologic structure of the mediastinum is in some measure dependent on the age of the animal and that the mediastinum in the dog resembles in the anatomic sense the greater omentum of the dog. He added, however, that it is not possible to determine on a purely histologic basis as to whether the function of both can be considered the same. Seifert showed, as is well known, that the mediastinum drains the pleura. Herrfarth[6] and others have pointed out that the pleural cavity drains readily to the mediastinum. We found that if india ink were injected into the neck it soon made its way to the mediastinum. When injected substernally above the level of the hilum of the lung, it soon found its way into the lung. When we injected india ink under the lower portion of the sternum it was observed after several weeks on the pericardium and pleura and in the mediastinum. But few ink particles were to be noted in the lungs.

The mediastinum also apparently contains cells which have phagocytic properties. The mediastinum of the rabbit has been found to be histologically and experimentally a denser and more resistant structure than that of other experimental animals. Between the pericardium and diaphragm, where the mediastinum surrounds the so-called bursa infracardiaca, the mediastinal pleura of the rabbit is made up of little fat nodules and fat conglomerate structures which resemble the similar bodies found in the greater omentum of the rabbit.

The mediastinal pleura of the human adult is denser and thicker than that of the child and than the analogous membranes of the various experimental animals. The mediastinal pleurae of the rabbit and monkey, Seifert stated, do not resemble the greater omentum in the same way as the mediastinal pleura of the dog which in this respect closely resembles that of man.

TECHNIC

Practically all our experiments were performed on rabbits, because the mediastinum of the rabbit is best fitted to stand stresses and strains—more so than other animals which would be suitable for such experimentations.

The arterial pressure was recorded by means of a cannula which had been introduced into the carotid artery and connected up with a mercury manometer. The venous pressure in the jugular vein was recorded by means of a water

5. Seifert, E.: Ueber den feineren Bau des Mediastinum, Arch. f. klin. Chir. **151**:237, 1928.

6. Herrfarth, E.: Beitrag zur Infektiösität der Pleura, Zentralbl. f. Chir. **41**:2582, 1928.

manometer which was fitted up with a cork rider and a very fine, thin-bored, glass recording arm. A glass tube was introduced into the trachea and recorded respirations on a tambour while the intrapleural and mediastinal pressures were recorded on two pneumothorax apparatus. Other details with regard to the technic of the experiments will be noted under the experiments which they concern.

The use of the pneumothorax apparatus together with the taking of roentgenograms at intervals and injections of iodized poppy seed oil 40 per cent performed at the end of the experiments in most instances enabled us to observe the presence or absence of a pneumothorax and quite often permitted us to recognize when a pneumothorax had developed. For although the development of a pneumothorax is often due to faulty technic, there are other occasions when it obviously means only that the increased mediastinal pressure was greater than the mediastinum could withstand.

ANATOMY OF THE MEDIASTINUM

The weak points of the mediastinum are under the sternum, where the thymus normally lies and behind the heart where both mediastinal pleurae come in contact. Two triangles are thus formed, the uppermost one having its apex where the heart begins and the lowermost one having its apex take off from the apex of the uppermost. The anatomic arrangement of the mediastinum, therefore, predisposes to the localization of fluids which collect in the mediastinum. But they do not become encapsulated. The resorptive powers of the mediastinum are greater than those of the pleural cavities or of the abdominal cavity.

It is perhaps best to consider that the mediastinum consists of an anterior and posterior compartment. The anterior mediastinum is made up of the so-called trigonum thymicum (mediastinum supracardiacum) and of the triangle occupied by the heart and great vessels. The anterior mediastinum, therefore, lies in front of the root of the lung, the posterior mediastinum behind the root of the lung.

In the mediastinum supracardiacum the first layer that one meets directly under the sternum is loose fatty tissue, which is, in man, for the most part, the remains of the thymus gland. Willis [7] has shown that the tracheobronchial lymph nodes of the rabbit are small but that the thymus is extremely large. The second layer is formed by the innominate veins and by the inferior thyroid veins and the internal mammary veins, both of which empty into the first mentioned veins. The next structure which is met and which lies for the most part in the midline is the superior vena cava. It is well to remember that the lower half of the superior vena cava is covered by pericardium and is therefore not visible. The great vessels in reality pierce the pericardium. The third layer is composed of the arch of the aorta and the branches which it gives off. The posterior portion of the third layer and the fourth

7. Willis, H. S.: Studies on Tuberculosis Infection, Tracheo-Bronchial Lymph Nodes of Rabbits and Their Blood Supply, Am. Rev. Tuberc. **14**:237, 1926.

layer composed of the trachea and the esophagus form the anterior wall of the posterior mediastinum. Other structures to be considered in the posterior mediastinum are the sympathetic nerves, the recurrent laryngeal nerves and lymph glands. The attachments of the diaphragm, the cardiophrenic angles and particularly the relationship of the various structures which leave the mediastinum and perforate the diaphragm are of extreme importance when considering the consequences of increased intramediastinal pressure. The foregoing descriptions concern in general the anatomy of man, but the anatomy of the rabbit in this region differs in no essential practical manner.

Under the mediastinal pleura, on either side of the mediastinum supracardiacum, lie the phrenic nerves and medial to them both the vagi, cardiac depressor and other nerves.

EXPERIMENTS WITH RUBBER BALLOON IN MEDIASTINUM

These experiments illustrate the effects of sudden confined increase in mediastinal content and pressure and how these effects can be made to disappear just as readily as they came by reducing the confined pressure, provided, of course, that the increased pressure is not kept up too long or the procedure repeated too often. The consequences, which were local and general, varied directly with the extent to which the balloon had been inflated and the position which it occupied in the mediastinum.

The usual technic was observed in these experiments. A little rubber balloon was attached to either a glass or rubber tube and connected up with a syringe or pneumothorax box and placed in the mediastinum.

EXPERIMENT 1.—The left intrapleural pressure was —8, and the right intrapleural pressure —10, 0. The mere taking of pneumothorax readings sometimes caused a slight temporary drop in blood pressure. Fifty cubic centimeters of air was injected into the balloon. Part of this air occupied the dead space in the glass tube. The left intrapleural pressure then became —14, and the right intrapleural pressure —4. An additional 50 cc. of air was then injected, and a roentgenogram showed no evidence of pneumothorax. The intramediastinal pressure was now sufficient to compress both the carotid artery and the trachea so that they were recorded on the tracing as straight lines.

EXPERIMENT 2.—The right intrapleural pressure was —4, —8, and the left intrapleural pressure —8, 0. Ten cubic centimeters of air injected into the balloon, which had been placed in the posterior mediastinum, caused a slight drop in blood pressure; after an additional 10 cc. of air had been injected, there was a gradual rise in blood pressure. The blood pressure remained unaffected after another 20 cc. of air had been injected. The roentgenograms showed no evidence of pneumothorax. The left intrapleural pressure was —6, 0, and the right intrapleural pressure —6, 0. Some of the air had in the meanwhile undoubtedly regurgitated. It was only after another 20 cc. of air and 6 cc. of iodized oil had been introduced into the rubber balloon that the left intrapleural pressure became —4, +2, and the right intrapleural pressure —2, +1. The animal died shortly afterward.

Postmortem examination showed the posterior mediastinum to be distended. There was a slight rent in the rubber balloon and some iodized oil had escaped. The anterior mediastinal septum and the heart were pushed over to the left. It is thus to be noted that in spite of an undoubted slight right-sided pneumothorax the mediastinal contents were apparently displaced to the same side as the pneumothorax. The diaphragm was not raised. The intercostal spaces were equal.

EXPERIMENT 3.—The same technic was employed that was used in experiments 1 and 2. After 5 cc. of air had been injected into the balloon, which had been placed in the posterior mediastinum, marked irregularity in the blood pressure and respiratory curve were noted. As the air in this experiment was injected by a syringe, it could be entirely released or kept in the balloon at will. A control

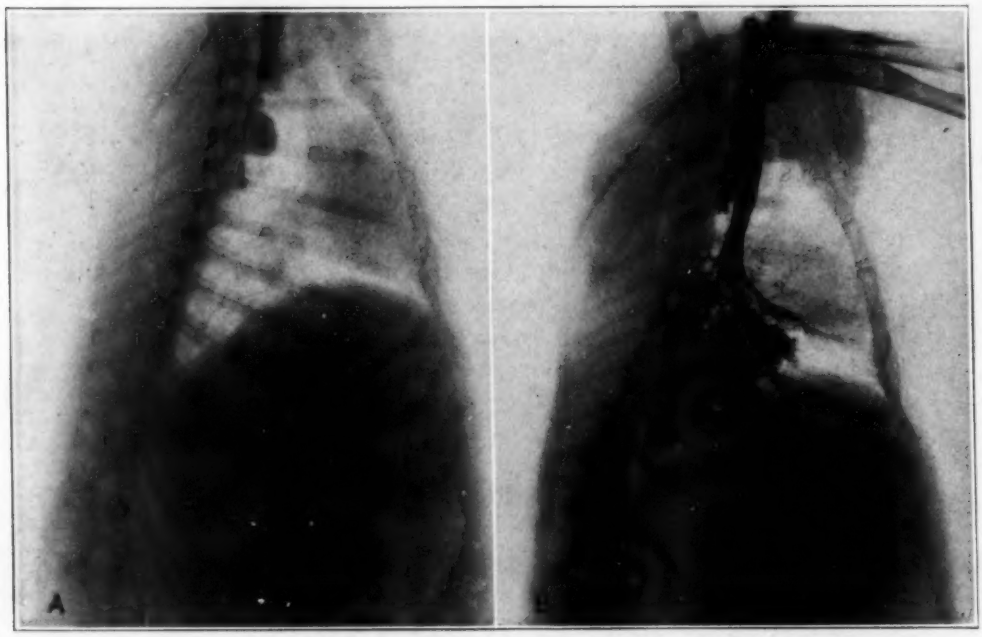


Fig. 1.—In *A*, note the rubber balloon which has been placed into the posterior mediastinum and inflated by 25 cc. of air. The balloon has also been visualized by making injections of iodized oil into it. The heart has been compressed against the sternum. During the experiment the balloon burst and air escaped into the posterior mediastinum, where it can be seen. *B* shows the same as *A*, except that 2.5 cc. of iodized oil has been injected intratracheally.

roentgenogram taken at this period showed no evidence of pneumothorax. The left intrapleural pressure was —4, 0, and the right intrapleural pressure —2, 0. Five cubic centimeters of iodized oil was then injected into the rubber balloon so that it could be visualized. This act was followed by extreme irregularities in the blood pressure curve, as the record indicates. The respiratory curve showed but slight oscillation. The trachea was undoubtedly compressed, and the resulting forced respiratory efforts were responsible for the marked changes in blood pressure. Several plates were then taken, and the lateral view (fig. 1*A*) suggested that some air had escaped into the mediastinum and perhaps into the pleural cavities. It was impossible to obtain any definite readings with the

pneumothorax needle because of the tracheal compression and consequent lack of respiratory excursion. The animal died in asphyxia, and a roentgenogram taken immediately after death showed the heart to be markedly dilated. The amount of cardiac dilatation was more than could have been expected even if the heart had ceased beating during diastole. The lower end of the rubber balloon was found to extend well down over the heart, and it had undoubtedly hindered heart action. A small amount of iodized oil was found in the right side of the thorax. The vessels of both hila were full, engorged and constricted above the engorgement, particularly the vessels of the right hilum. There was a small amount of clear fluid and air in the pericardial sac. The balloon was still much distended and also occupied the greater part of the posterior mediastinum. A small rent in the balloon was discovered. The left lung was fully distended, that is, in almost full inspiration. The right lung was somewhat shrunken and atelectatic, but not in

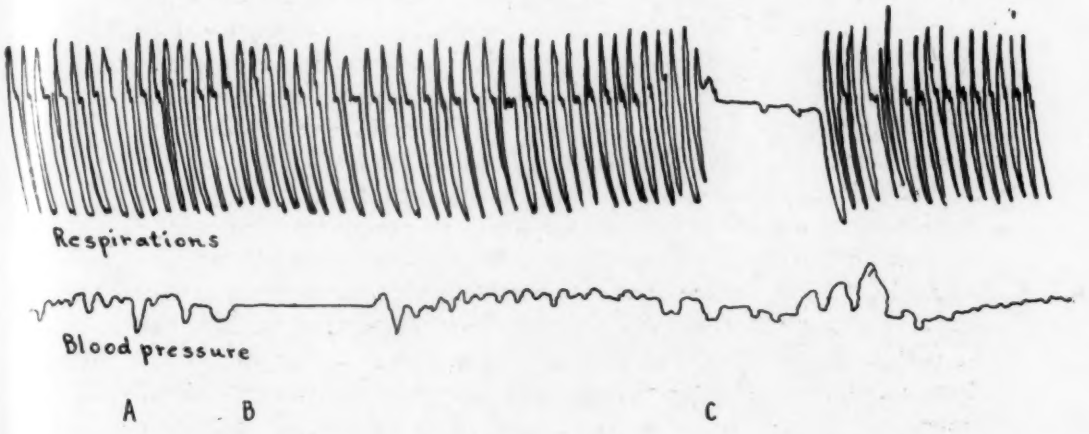


Fig. 2 (experiment S).—On Dec. 5, 1928, a rabbit weighing 3 Kg. was given 1.1 Gm. of sodium barbital intraperitoneally. A rubber balloon was placed in the posterior mediastinum and was connected with a syringe. Six cubic centimeters of air had previously been injected but allowed to escape. At *A*, 2 cc. of air was injected and then allowed to escape from the balloon. At *B*, 5 cc of air was injected, and the blood pressure curve was registered as a straight line. When the injected air was allowed to escape, the blood pressure was again registered. At *C*, 4 cc. more air was injected and temporarily not allowed to escape from a rubber balloon which this time compressed the trachea.

the phase of what would be considered complete and full expiration. The right lung showed marked patchy pulmonary emphysema. The upper lobe of the left lung showed peripheral emphysema. Both lungs were congested, particularly the right. The inferior vena cava was compressed at one point. This was perhaps due to the downward displacement of both diaphragms and also to the presence of free air in the posterior mediastinum. The posterior mediastinum was so distended that on ordinary inspection of the roentgenogram just after death a pneumothorax was suspected.

The initial change in the blood pressure following the injection of air into the rubber balloon which was placed in the mediastinum was always a fall in blood pressure. This fall in blood pressure was perhaps more marked when the balloon was in the anterior mediastinum. This might be expected, for a sudden increase in the vertical diameter of the rubber balloon would of necessity more directly impair heart action and be more likely to compress the great vessels. Compression of blood vessels, particularly of veins, was found constantly in this series of experiments. If when the blood vessels at the root of the lung were compressed the main bronchus was also encroached on, then the lung would be even more collapsed (hypoventilation) although peripheral emphysema could be present and the corresponding diaphragm not necessarily elevated. The opposite lung would be overdistended and give evidence of marked compensatory emphysema (hyperventilation). The liver was also observed to be engorged on several occasions. We did not observe any such gross changes in the spleen, but such changes were suggested in the kidneys on three occasions.

When the foregoing experiments were repeated and the injected air aspirated or allowed to escape, then the blood pressure and respirations which were registered as a straight line would immediately return to normal. Throughout such an experiment it would be the blood pressure and not the respirations which would show the most marked changes. If the mediastinum is repeatedly acutely distended and the trachea or a main bronchus compressed, then pulmonary emphysema will usually develop.

Graham [8] has shown that distention of the capillaries induces a diminution rather than an increase in the size of the alveoli. He was able to show experimentally that the alveoli of the lobe the capillaries of which were distended were much smaller than the alveoli the capillaries of which were not distended.

TRACHEAL FISTULAS

By cutting out windows in the trachea at various levels, it was possible to study the production of mediastinal and subcutaneous emphysema in a manner which is quite similar to that occurring in man as a result of injuries to the trachea and bronchi.

When the trachea was being operated on, slight irregularities in the blood pressure and respiratory curves were noted but there was soon a return to normal. When a window was made in the trachea low down and posteriorly, then mediastinal emphysema developed fairly regularly. The emphysema extended to the anterior mediastinum and was to be

8. Graham, E. A.: Cautery Pneumectomy, personal communication to the authors.

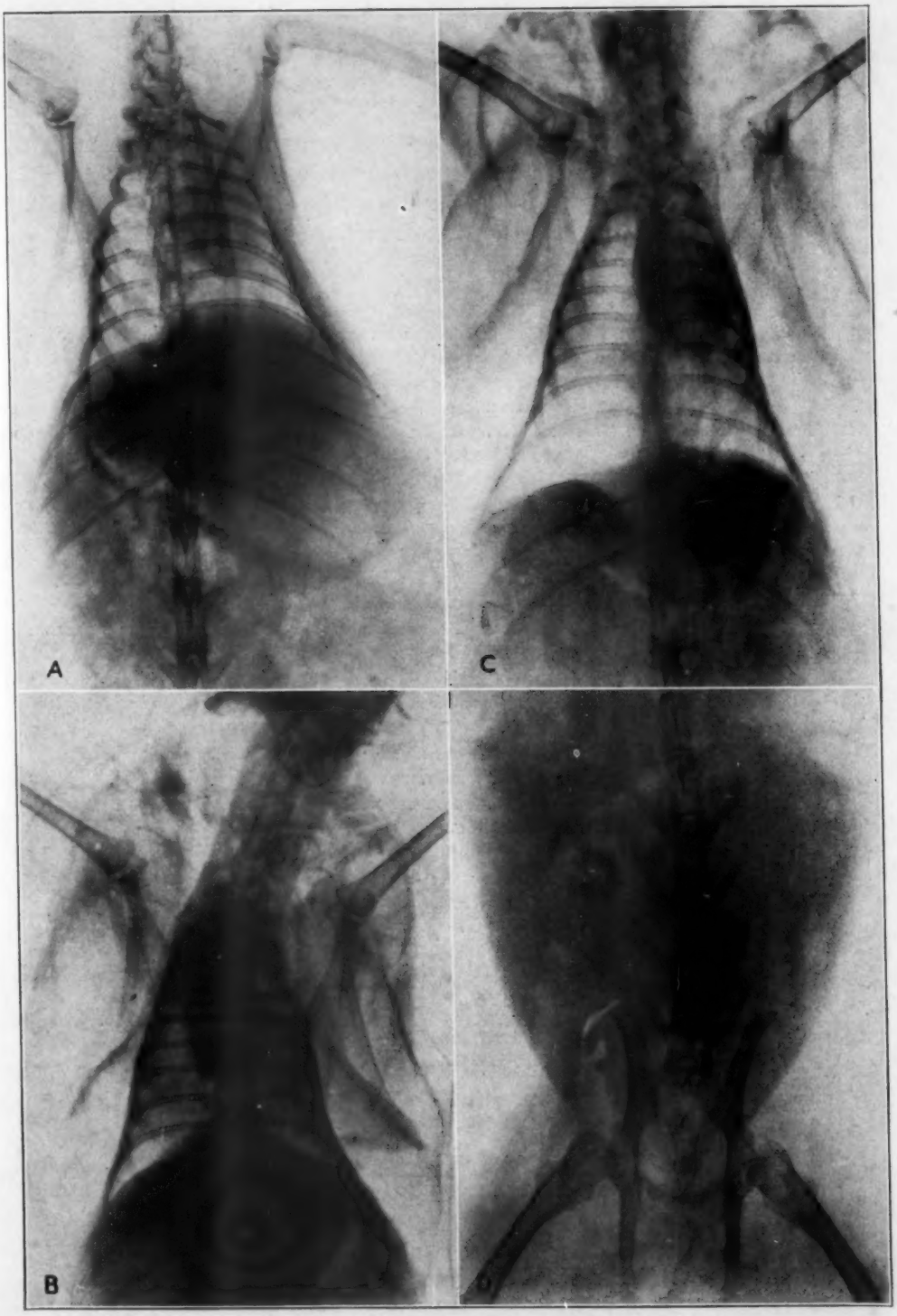


Fig. 3 (experiment 4).—*A*, normal control plate. *C* shows that the thorax has increased in size. The diaphragm has descended. The intercostal spaces are widened. The heart has been displaced to the right. Air has dissected retroperitoneally and has outlined the kidneys and perirenal tissues and has even extended to the lower limbs. In *B*, note the tremendous subcutaneous emphysema which developed in a rabbit consequent to the production of an experimental tracheal fistula. Note also the sharp outline of the muscles of the neck and of the skeleton, and the size and position of the heart, diaphragm and the thorax as a whole. Plates of the upper (*C*) and lower (*D*) portions of the body have been joined to each other to give a view of the whole body.

particularly noted dissecting up the mediastinal surface of the sternum. It also spread to the limbs over the anterior wall of the chest and in the axillae following along the fascial sheaths of the axillary vessels. The thorax on certain occasions actually increased in size, as the following experiment demonstrates.

EXPERIMENT 4.—At 10:40 a. m., control roentgenograms were taken. A triangular window was then made in the trachea posteriorly and low down. The trachea was then allowed to drop back and the muscles and skin sutured tightly. A lateral roentgenogram showed that the thorax had definitely increased in size. At 11:06 a. m., the left intrapleural pressure was —6, —4 and the right intrapleural pressure —2, —7. At 2 p. m. (fig. 3, *B* and *D*), marked subcutaneous emphysema was noted. Marked collections of air were to be noted in the neck and axillae and to a lesser degree along the lateral aspects of the lower abdominal wall. Posteriorly, the emphysema stopped at the superior nuchal line. At 2:05 p. m., both intrapleural pressures were —6, 0. The animal had been under great respiratory distress for some time. Dyspnea was marked and respirations were noisy. The animal was then photographed. After a few convulsive kicks, the animal died (4:25 p. m.). Roentgenograms were now taken and showed that the thoracic cavity had increased in size. The intercostal spaces were widened and the heart definitely displaced to the right. The extensive emphysema presented a picture which suggested a bilateral pneumothorax.

Both kidneys appeared to be outlined by air which had dissected down into the retroperitoneal spaces. That such was the case was verified at necropsy. The x-ray shadow which suggested an air outline of the kidneys and perirenal tissue could be definitely differentiated from the diaphragm. Emphysema of a considerable degree could be observed in the anterior and posterior mediastina. Both lungs showed evidences of pulmonary emphysema.

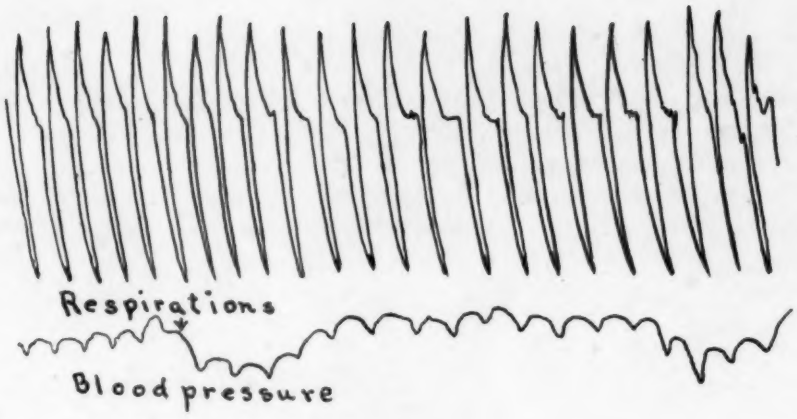
THE COURSE AIR MAY TAKE IN THE PRODUCTION OF MEDIASTINAL AND SUBCUTANEOUS EMPHYSEMA

The air which reaches the mediastinum may take several courses. It may spread subfascially (Brauer [9]), that is, between the costal pleura and the intrathoracic fascia. In man, air which collects in the mediastinum may give a sharp contour to the great vessels.

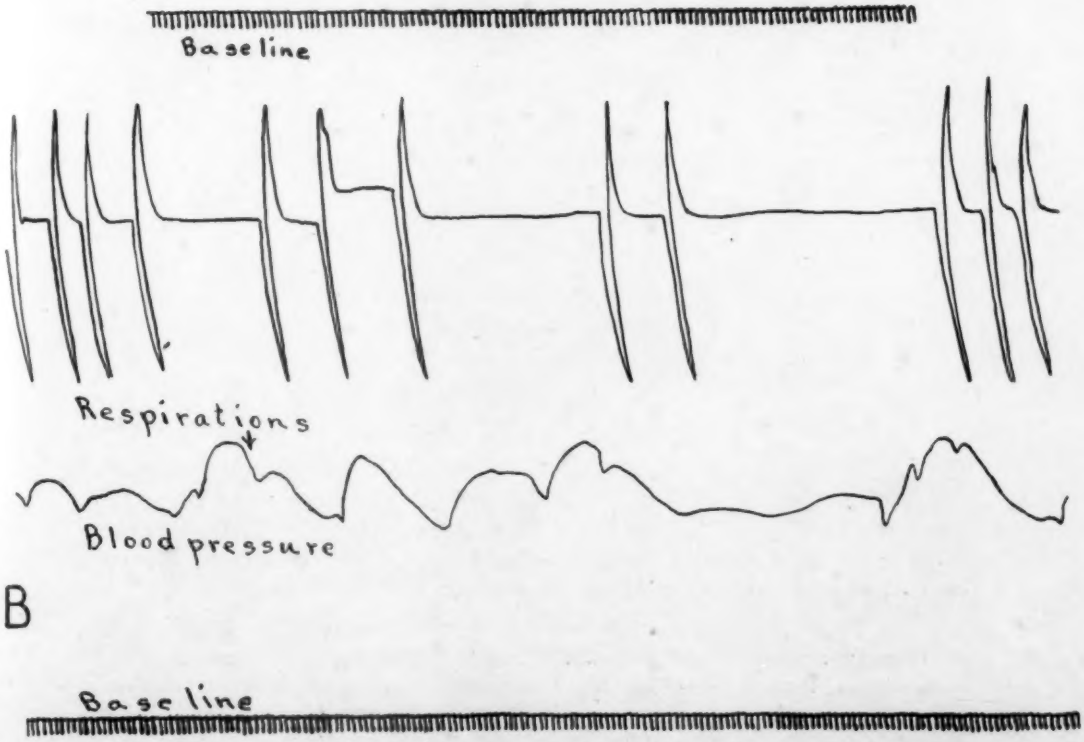
The most severe type of mediastinal emphysema results, as Sercer and Peicic [10] have pointed out, when the lung itself is injured, as during pneumothorax treatment. So, too, rupture of an emphysematous bleb or of a cavity may allow air to dissect at first interstitially and then to the hilum of the lung; from thence into the mediastinum subfascially and even over the entire body. It is possible for air to dissect up all along the trachea to the floor of the mouth, extending under the base of the tongue which becomes raised. So, too, it is well to remember that the air follows with predilection the normal fascial planes, particularly the sheaths which surround blood vessels. The axillary and femoral

9. Brauer, cited by Sercer and Peicic: Beitr. z. Klin. d. Tuberk. **53**:123, 1922.

10. Sercer, A., and Peicic, R.: Ein Beitrag zur Kasuistik der Todesfalle beim künstlichen Pneumothorax, Beitr. z. Klin. d. Tuberk. **53**:123, 1922.



A



B

Baseline

Fig. 4.—In *A*, the two drops in blood pressure noted in the curve represent the effect of the injection of 10 cc. of air into the anterior mediastinum. *B*, this portion of the original tracing (*A*) was recorded after 10 cc. of air had been injected into the anterior mediastinum. This amount was injected over a period of about one hour in five separate amounts.

vessels may thus be compressed. Then again, not only may the air extend retroperitoneally and outline the kidneys, but we have observed it around the renal vessels and ureter.

When the trachea is injured then the air may dissect downward, and when it dissects from above down, the subcutaneous emphysema is usually marked and mediastinal emphysema exists to a lesser degree. Severe mediastinal emphysema may also develop from a tension pneumothorax.

Fig. 5.—Anterior mediastinal emphysema. A window has been made in the lateral wall of the chest and the lungs have been allowed to drop back. Air had previously been injected into the anterior mediastinum. Note the emphysematous blebs in the loose tissue of the anterior mediastinum. The pericardium, which also shows emphysematous blebs, has been opened.

Experiment 5.—At 3:47 p. m., the initial right intrapleural pressure was —6, —8, and the left —8, —10. A low left anterior tracheotomy was performed. At 4:20 p. m., the blood pressure registered 95 mm. of mercury, which indicated a slight rise. At this stage of the experiment pressure on the animal's neck or axillae would cause a slight drop in blood pressure. At 4:34 p. m., the blood pressure was 100 and both pleural pressures —12, —10. The animal's limbs were

then released. This relieved skin tension. Slightly more subcutaneous emphysema then developed. At 5:08 p. m., the left intrapleural pressure was —2, —10, and the right intrapleural pressure —8, —6. The skin over the neck was bluish. The blood pressure was 45 mm. of mercury. Respirations were now labored and rapid. Definite emphysema could be observed over the right side of the thorax. The entire thorax seemed to move as a whole. At times the excursions of the right side of the chest were a little more marked than the left. The fistula in this animal was so placed that the surrounding tissue could partially occlude it; hence, mediastinal emphysema was not marked. In none of these experiments did the

Fig. 6.—Posterior mediastinal emphysema. Drawing from actual specimen. Note how the "emphysema" surrounds and compresses the trachea, esophagus and vessels at the root of the lung. The right lung is somewhat collapsed.

injected iodized oil make its way into the mediastinum. This was, in all probability, due to the accumulation of secretions within the trachea, to the viscosity of the oil and to the fact that the surrounding tissues always partially occluded the opening in the trachea.

In the foregoing experiments with tracheal fistulas, when mediastinal emphysema was marked, then subcutaneous emphysema was slight, and vice versa. The animals in these experiments usually died from the

consequences of mediastinal and subcutaneous emphysema, from mediastinitis, or from a pneumonic process which was usually severe. Combinations of the foregoing conditions also occurred. Thus, in animal 4, a window had been made in the trachea low down and posteriorly. The animal died on the third day. Subcutaneous emphysema could be noted over the neck and thorax, and slight emphysema in the anterior and posterior mediastina. A pneumonic process could be demonstrated in the left upper lobe, also patches of pneumonia throughout the right lung. A whitish sticky secretion could be expressed from the trachea. The neck wound was quite clean, and the fistulous opening slightly infected.

Gold [11] has shown that in dislocating the thyroid gland during thyroidectomy air can be sucked into the mediastinum. He added that mediastinal emphysema is a typical complication of substernal strumectomy and that the collections of air which can be demonstrated remain for some time. He further noted that the treatment of mediastinal emphysema with the negative pressure apparatus ("Unterdruck Apparat Lebsche-Sauerbruch") does not give satisfactory results in such cases. It is not uncommon to find blood staining the entire mediastinum after operations in the neck.

Mediastinal emphysema has been observed after pulmonary lobectomy, both clinically and experimentally. Graham,[8] in a large series of cautery pneumectomies, never observed mediastinal emphysema after this procedure. In a series of experiments on lung healing (Olch and Ballon [12]), although portions of lung tissue were excised and middle sized bronchi were cut across, in no instance did mediastinal emphysema develop. In one animal, at the suggestion of Dr. Graham, large bronchi were cut across and were then intentionally sutured so that there was absolutely no apposition of the cut ends of the bronchi. Tremendous mediastinal and subcutaneous emphysema resulted. The animal died on the fourth day. The lung wound appeared to be healed. An injection of iodized oil failed to show any injection of the lung tissue beyond the points where the bronchi had been cut off. Although some air may have escaped into the pleural cavities, quantities of air must also have escaped from the interstitial tissue to the root of the lung. In this instance air was noted even under the base of the tongue and around the ureter.

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11. Gold, E.: Ueber Mediastinalemphysem nach Strumektomie, Mitt. a. d. Grenzgeb. d. Med. u. Chir. **37**:352, 1924; discussion in Arch. f. klin. Chir. **138**:195, 1925.

12. Olch, I. Y., and Ballon, Harry C.: Experimental Lung Abscess Following Ligation of the Pulmonary Artery, unpublished communication.

THE EFFECTS OF THE INJECTION OF AIR INTO THE ANTERIOR AND POSTERIOR MEDIASTINA

We noted in the following experiments that when the injected air was given sufficient time to spread and diffuse, the blood pressure would

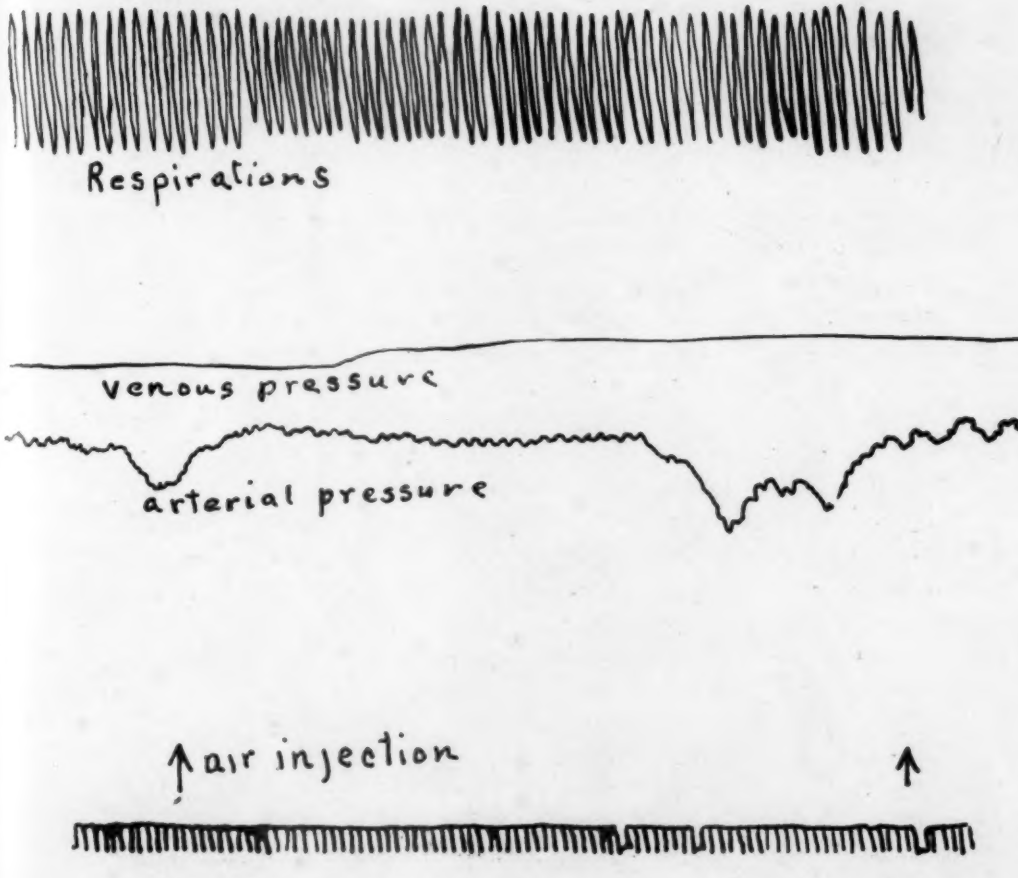

Fig. 7.—Tracing which shows the changes in venous pressure and arterial pressure following the injection of small quantities of air into the anterior mediastinum.

again return to normal in several instances. For, if the quantity of air injected were not too great, then after the air had diffused the heart action would become free. It has been shown, and we were able to verify the fact, that large amounts of blood can apparently become stag-

nant in the lung without producing marked pressure changes in either the greater or lesser circulations (Straub [13]).

It is also to be noted that mediastinal pressure can become definitely positive before pneumothorax need develop.

EXPERIMENT 6.—A rabbit weighing 2 Kg. was given 1 Gm. of sodium barbital intraperitoneally and was prepared in the usual way. The initial intrapleural and mediastinal pressures were all negative. After 150 cc. of air had been introduced into the mediastinum, the right and left pleural pressures were 0, —6. The mediastinal pressure was +2. Two roentgenograms were then taken but did not show any evidence of pneumothorax. Shortly afterward, the left intrapleural pressure became +6, the right —10, —5 and mediastinal pressure 0. Further

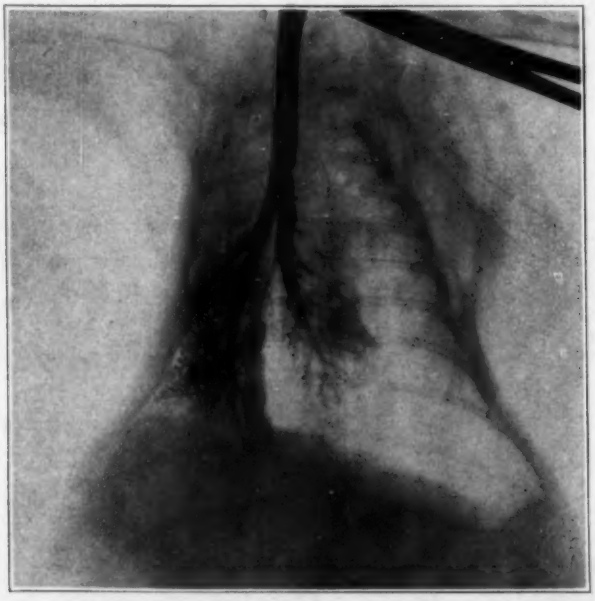

Fig. 8.—Right pneumothorax. This figure demonstrates that unilateral pneumothorax is possible in a rabbit. The bronchial tree has been outlined by the injection of iodized oil. An ordinary roentgenogram in this instance suggested a bilateral pneumothorax.

injection of air produced asphyxia and caused the death of the animal. The left side of the diaphragm was found to be ballooned out, almost eventrated and much lower than the right side. The heart was compressed against the sternum and the left lung slightly collapsed. There were evidences of anterior and posterior mediastinal emphysema.

EXPERIMENT 7.—A rabbit, weighing 2.6 Kg., received 0.78 Gm. of sodium barbital intraperitoneally, and adequate general anesthesia was given. Air was then injected into the anterior mediastinum through a needle which was connected

13. Straub, H.: Ueber den kleinen Kreislauf, Deutsches Arch. f. klin. Med. **121**:394, 1917.

with a pneumothorax apparatus. The right intrapleural pressure was 0, the left intrapleural pressure —4, —2, and mediastinal pressure —2, —4. After control plates had been taken, 75 cc. of air was injected into the anterior mediastinum. The right intrapleural pressure was then —4, —6, and the left —4, —7. Another 50 cc. of air was then injected. A fall in blood pressure, an increase in the respiratory rate and a shortening of the respiratory excursion followed. The blood pressure soon returned to normal, although the respirations continued to be shallow. Another 50 cc. of air was injected and produced even a more marked drop in blood pressure. The left intrapleural pressure was +2, +6, and the right

Fig. 9.—Heart tamponade. This drawing illustrates an experimentally produced hemopneumopericardium. The heart muscle had been directly lacerated. Air entered the pericardium and also the anterior and posterior mediastina and produced the large emphysematous blebs which compressed the lungs, as illustrated. These emphysematous blebs occupied the greater portion of the lower part of the thorax and suggested the presence of a pneumothorax.

—4, —6. From this stage on, whenever the pneumothorax needle was introduced into the pleural cavity a definite but temporary fall in blood pressure would occur. After another 50 cc. of air had been injected, the mediastinal pressure became +8, the left intrapleural pressure +6, +8, and the right +2. A marked fall in blood pressure was now observed. Respirations were regular. Five minutes after this last injection of air, the animal began to show definite signs of asphyxia. The

left intrapleural pressure was then + 22, and the right + 6 (cm. of water). The roentgenogram revealed a definite left-sided pneumothorax and suggested the presence of a small amount of air in the right costophrenic angle. The animal soon died. The heart and mediastinal contents were found to be displaced well over to the left. Subcutaneous emphysema and mediastinal emphysema were evident. No mediastinal tear could be demonstrated even though iodized oil was injected into the mediastinum under considerable pressure. The pressure exerted, however, may have been entirely expended in forcing the iodized oil through the needle.

It becomes evident that just as mediastinal emphysema may be a consequence of a pneumothorax, so may a pneumothorax in certain instances undoubtedly be due to what was originally a mediastinal emphysema. Sauerbruch [14] has shown that mediastinal emphysema may be a consequence of a tension pneumothorax and that the reverse may also occur. It would, therefore, seem likely that a tension pneumothorax may later develop into a mediastinal emphysema, the result of a pneumothorax or even of mediastinal emphysema. It is well to remember that the cardinal signs of penetrating wounds of the thorax are subcutaneous emphysema, pneumothorax and bleeding (Haim [15]). If the lung itself has been injured, then the subcutaneous emphysema is usually an expression of mediastinal emphysema. In a discussion on injuries of the lungs as a result of contusions of the wall of the chest, Sauerbruch [16] noted that, if the trachea is tied off and the wall of the chest traumatized, in 50 per cent of instances in the experimental animal a rupture of the lung will occur. One of the consequences is pneumothorax, and it is in such cases as we have already noted that the severest type of mediastinal emphysema may develop. Before mediastinal emphysema does develop, however, the affected pleural cavity becomes distended and the lung collapsed. The enclosed air, therefore, can compress the heart, other mediastinal contents and the opposite lung. Air continues to enter the affected thorax even though the lung is collapsed because air can enter the main bronchus and can escape through the tear in the lung. If there is in addition a tear in the mediastinal pleura, then a tension pneumothorax may develop and subsequently mediastinal and subcutaneous emphysema.

It has been shown that the lung tissue may be so injured that when air enters through the bronchus it can escape into the loose tissues, but that during expiration the injured lung tissue around the open bronchus

14. Sauerbruch, F.: Die Bedeutung des Mediastinalemphysems in der Pathologie des Spannungspneumothorax, Beitr. z. klin. Chir. **60**:450, 1908.

15. Haim: Ueber penetrierende Thoraxverletzungen, Deutsche Ztschr. f. Chir. **79**:269, 1905.

16. Sauerbruch, F.: Die Chirurgie der Brustorgane, Berlin, Julius Springer, 1925.

is sucked into the lumen of the tear in the lung if it includes a bronchus; hence, the inspired air which has been drawn into the injured pleural cavity cannot be expired and cannot escape except through the routes previously mentioned. Pain could also cause a splinting of the affected side; and as cough when the glottis is closed would tend to increase the intrapulmonary pressure, this factor would also tend to keep the tear in the lung from closing.

It is difficult to prove that the mediastinum which separates the pleural cavities enables them to function independently. Figure 8 shows how in a unilateral pneumothorax in a rabbit the mediastinal contents can be pushed right over into the opposite side of the chest. This observation, of course, agrees fully with the mobility of the human mediastinum and the tendency of changed pressures to become equalized throughout the thorax, which were extensively discussed by Graham. We studied the degree of pneumothorax which developed after death in one animal. We observed no evidence of pneumothorax fifty-five minutes after the death of the animal.

In determining venous pressures by the method already referred to, no sharp sudden changes were noted. Only gradual rises and falls in the venous pressure were observed. By the method which we employed, it is occasionally possible to demonstrate slight changes with the phases of respiration. In animal 14, air in quantities of 10 cc. was injected into the anterior mediastinum and rises of 3 cc. were noted in the water manometer. Our experiences with venous pressures in these experiments do not permit us to make any absolute statements. For at times the injection of a small quantity into the mediastinum will produce a rise in venous pressures and on other occasions a drop. Nor need there be, according to our present experience, a rise in venous pressure when there is a fall in arterial pressure, although transitory terminal rises in venous pressure (preasphyxial and asphyxial) concomitant with the fall in arterial pressure could be observed.

The following experiment illustrates how the picture of pressure on the pericardium and of heart tamponade resembles that due to mediastinal emphysema (Sauerbruch).

HEART TAMPONADE

The left intrapleural pressure was —4, —12, and the right intrapleural pressure —6, —10. Whenever a needle was pressed against the pericardium, slight irregular falls in blood pressure were noted. The blood pressure quickly recovered when the needle was withdrawn. When the needle was inserted into the pericardium from the lower end of the sternum, then a drop in blood pressure of 20 mm. of mercury was noted. Any pressure on the needle, no matter where it was placed over the heart, always caused a fall in blood pressure. The fall in blood pressure was apparently directly proportional to the pressure exerted. No significant changes in respiration were noted, although the respiratory excursion

sometimes became smaller and the rate somewhat slowed. When an incision was made over the lower aspect of the sternum, then the blood pressure dropped and grew irregular, and respirations became rapid. When a large sucking wound had been produced in the pericardium, the animal soon succumbed. At necropsy, a small opening was found in the pericardium. A hemopneumopericardium was present. There were also large emphysematous blebs in the anterior mediastinum and some emphysema in the posterior mediastinum. The lungs showed marked peripheral emphysema.

It is to be noted that some blood escaped from the animal's mouth before death. Where this blood came from was not quite certain. It is known that when the intrapulmonary pressure is reduced, bleeding from the lung may occur

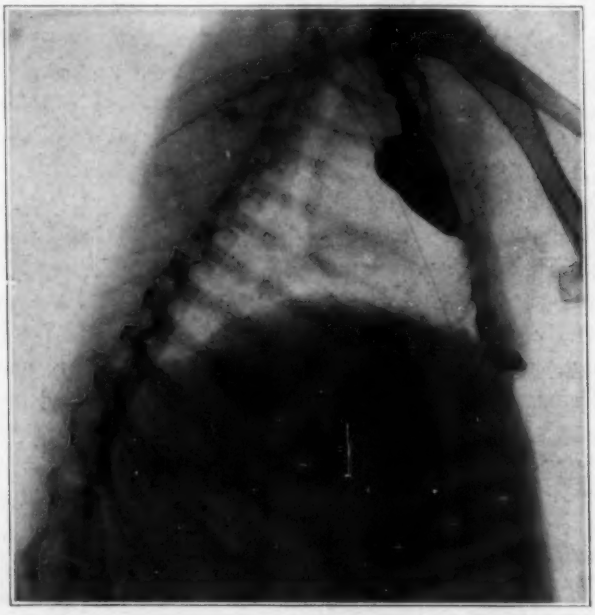

Fig. 10.—Introduction of a solid into the anterior mediastinum. Three cubic centimeters of a mixture of paraffin and iodized oil have been injected into the anterior mediastinum and have solidified. This mass caused some compression of the mediastinal contents, particularly of the trachea. The animal died of edema of the lungs. There were, in addition, some evidences of pulmonary emphysema. The heart was large. The tracheal mucous membrane was reddened.

(Hoffmann [17]). The question might be raised, however, as to whether or not the pulmonary emphysema in this case may not have been due to some aspirated blood. The roentgenograms taken after death were misleading because the emphysematous blebs crowded the left side of the thorax and therefore suggested a pneumothorax. The liver was somewhat engorged with blood The more immediate cause of the death of the animal was undoubtedly due to the effects of the so-called heart tamponade.

17. Hoffmann, F. A. Erkrankungen des Mediastinums, in Nothnagel: Specielle Pathologie und Therapie, 1896, vol. 13, p. 1.

EFFECTS OF THE INJECTION OF MIXTURES OF PARAFFIN AND IODIZED OIL INTO THE ANTERIOR AND POSTERIOR MEDIASTINA

The effects of the injection of paraffin and iodized oil into the mediastinum depends entirely on the size and position which the mixture occupies after it has solidified. All substances that we used failed to produce any immediate irritative reactions. It is well to remember, however, that if the trachea or esophagus is transfixed, inflammatory processes may result (Ballon [18]).

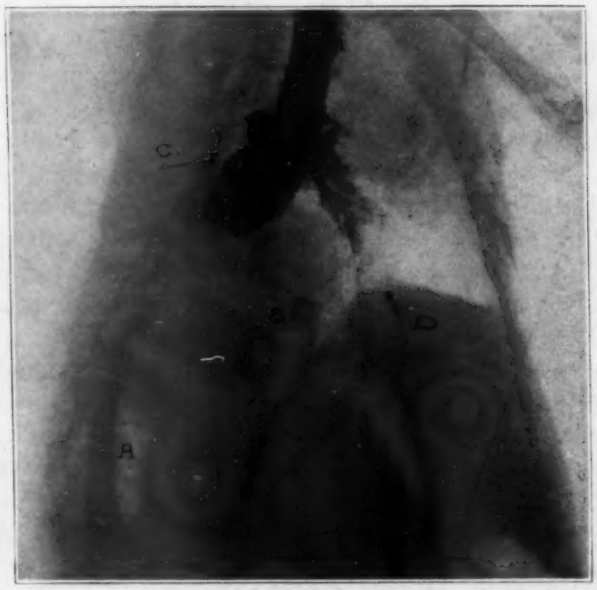

Fig. 11.—Intrathoracic hernia. *A* indicates air in the posterior mediastinum; *B*, the stomach with a small amount of iodized oil in it; *C*, how the lungs are compressed against the vertebral column, and *D*, the irregularity of the diaphragm.

When solids are placed above the jugulum, they may produce absolutely no distress. They can, however, compress blood vessels, particularly veins and, although the pressure within these compressed veins may undoubtedly increase, still nothing more than that these veins become dilated need occur, although local parts through pressure might thus be somewhat deprived of their nutrition. One rabbit which received a substernal injection of a mixture of 3 cc. of iodized oil and paraffin showed no immediate distress but during the day died of what proved to be edema of the lungs. In another instance, the injection of

18. Ballon, H. C.: Lipiodol bei der Lungentuberkulose; Eine experimentelle klinische und pathologische Studie, Frankfurt. Ztschr. f. Path. **36**:207, 1928.

a similar amount of the same mixture failed to produce any change in the blood pressure or in the respirations. When a slight pressure which under ordinary circumstances would have produced no effect was then applied to the thorax, irregularities in the amplitude of the respiratory excursions were noted which disappeared when the pressure was removed. The same occurred when pressure was exerted over the thorax after some of the injected mass had been allowed to solidify over the heart.

If a needle which had been introduced into the mediastinum was merely allowed to rest on the great vessels, a slight fall in arterial blood pressure and irregularities in the respiratory curve were noted. If air in quantities of a few cubic centimeters was then injected, further slight falls in arterial blood pressure were noted and the respiratory excursions became smaller.

It would seem that a fluid can spread almost as readily along the anterior mediastinum as along the posterior mediastinum. A solid mass in the anterior mediastinum of sufficient size to compress the lung must of necessity at the same time compress some of the blood vessels. At necropsy all that may be noted when such is the case is slight lateral compression of the trachea, edema of the tracheobronchial mucous membrane and some pulmonary emphysema.

It is interesting to note that Gaisford [19] passed an endotracheal catheter before death in six children who died from status thymicolymphaticus. There was no evidence of tracheal compression, although the tracheal mucous membrane was slightly injected. The introduction of air through the catheter failed to improve the cyanosis or dyspnea. At post mortem, the large vessels of the neck were found dilated.

Nissen [20] has shown that when substances, practically the same as those which we employed, were injected into the mediastina of rabbits and allowed to remain there over a considerable period of time the changes in blood pressure noted were similar to those which we have already described.

Nissen and Cokkalis [21] have shown that prolonged tracheal stenosis leads to hypertrophy and dilatation of the right side of the heart. The edema of the lungs which may develop in this connection predisposes to bronchopneumonia. They apparently consider that the edema of the lungs which develops in tracheal stenosis is due to (1) the sudden

19. Gaisford, W.: Status Thymico-Lymphaticus, personal communication to the authors.

20. Nissen, R.: Experimentelle Untersuchungen zur Theorie des Entstehung des Lungenemphysems, Deutsche Ztschr. f. Chir. **200**:177, 1927.

21. Nissen, R., and Cokkalis, P.: Experimentelle Untersuchungen ueber mechanische Atmungsstörungen und einige Folgezustand, Deutsche Ztschr. f. Chir. **194**:50, 1925.

reduction in intra-alveolar pressure within the emphysematous nonyielding alveoli and (2) the impaired action of the hypertrophied right ventricle (Cohnheim-Welch). The amount of blood in the lung will therefore depend not only on the size of the lung but also on the state of the entire thorax, including the position of the diaphragm.

Changes in either intrapleural or mediastinal pressure must affect the intra-alveolar pressure in some way or other.

The pulmonary emphysema which may develop consequent to mediastinal emphysema also tends to narrow the mediastinum. Widening of the thorax in the experimental animal (Nissen [22]) does not lead to hyperventilation or to substantial emphysema. Widening of the thorax occurs only when the acting mechanism which will produce pulmonary emphysema lies directly or indirectly in relation to the tracheobronchial tree (Alexander and Kountz [23]). Hyperventilation and emphysema are but degrees of the same process, according to Aschoff and Tendeloo. Hypoventilation and atelectasis may therefore be considered phases of the reverse condition.

In no instance did we observe grossly any evidence of edema of the mediastinum, and fluid in the pleural cavity in only one instance. This occurred when mediastinal emphysema developed from the subcutaneous injection of air.

Concerning the absence of mediastinal edema in any of our animals which developed mediastinal emphysema, it will perhaps not be amiss to refer to a recent paper by Granström.[24] He remarked that he often found signs of dulness to the right of the sternum which apparently developed from and had something to do with stasis in the larger vessels of the thorax. He mentioned that the lesion of the heart in such instances was either one of myocarditis, aortic or mitral endocarditis, or arteriosclerosis. Pulmonary emphysema was present in some but absent in others. The heart was sometimes small and, at other times, enlarged. Granström also observed the condition which he considers to be mediastinal edema in patients suffering from heart disease who showed no evidence of "Stauungs erscheinungen" elsewhere. He noted further that the extensive edema in the anterior mediastinum may displace the medial lung border of the upper lobes outward and that portions of the lobes so displaced may become airless. Some of Granström's patients have come

22. Nissen, R.: Kreislaufwirkung umschriebener Drucksteigerung im Mittelfellraum, Deutsche Ztschr. f. Chir. **208**:59, 1928.

23. Alexander, H. L., and Kountz, W. E.: Studies on Emphysema, to be published.

24. Granström, E.: Ueber Erweiterung der vena cava superior und anonymae und ueber Oedem des Mediastinums bei Herzinsuffizienz, Wien. klin. Wchnschr. **9**:264 (Feb. 28) 1929.

to necropsy. Granström also noted that in certain severe cases of pulmonary emphysema this mediastinal edema may be absent, and that it may be present when there is no pulmonary emphysema. Widening of the superior vena cava and the innominate veins is in his estimation directly responsible for the mediastinal edema.

It is to be remembered that the great vessels may become elongated and tortuous in certain cardiac conditions and yet the size of the heart remains unaffected. In this way any elongation of the aorta makes the subclavian arteries more readily palpable.

The following experiment concerns an artificially produced intrathoracic hernia which for the most part occupied the inferior portion of the posterior mediastinum. This condition must be differentiated from mediastinal hernia which is really a gaseous displacement of the mediastinum but which may in turn be aggravated by any increase in intramediastinal pressure.

MEDIASTINAL INTRATHORACIC HERNIA

RABBIT 7.—To an animal weighing 2.9 Kg., 8.7 cc. of sodium barbital was given intraperitoneally. Right intrapleural pressure was —4, —6, and left intrapleural pressure —4. An incision was made in the midline. A slight fall in blood pressure was noted when the peritoneal cavity was opened and the abdominal organs, particularly the stomach, were handled. If they were left alone then the blood pressure would rise beyond its former height. Respirations would be slightly irregular and expiration at times quite deep. When the left side of the diaphragm was pushed up from below, then the respiratory and blood pressure excursions became less marked. The esophageal portion of the stomach was then mobilized. This act caused a marked temporary drop in blood pressure. Any pull on the stomach or gastrohepatic ligament produced irregularities in the blood pressure and respirations. This was particularly marked when that portion of the stomach which received the main vagus fibers was handled. A general increase in blood pressure resulted from the latter procedure. The mobilized part of the cardiac portion of the esophagus and a small portion of the esophagus could now be herniated through the esophageal opening of the diaphragm. Respirations now became irregular, and the blood pressure began to fall. The intra-abdominal portion of the stomach became dilated. Both diaphragms were elevated. The animal died soon after the abdomen was closed. Injections of iodized oil were made into the esophagus and lungs. Necropsy verified the roentgen observations. There was slight mediastinal emphysema, air having entered the thorax through the esophageal opening of the diaphragm. Both lungs were compressed. The heart was pushed up against the sternum, the inferior vena cava against the vertebral column.

Just as an increase in the size of the mediastinal contents may affect the position of the diaphragm, so may the position of the diaphragm affect the position of the structures in the mediastinum, particularly when there are pleuropericardial adhesions. Any process which encroaches on the costophrenic angle or the mediastinum may narrow

the space occupied by the inferior vena cava and appreciably disturb the inflow of blood through the inferior vena cava. An intrathoracic hernia through one of the normal openings in the diaphragm might readily accomplish this. When the margins of the lungs are pushed apart by anything which comes to occupy the anterior mediastinum, then the blood vessels in this neighborhood come to lie more directly on the vertebral column.

CAUSES OF SPONTANEOUS MEDIASTINAL EMPHYSEMA AS REPORTED IN THE LITERATURE

Jehn and Nissen [1] have stated that mediastinal emphysema was once reported after a pneumoperitoneum.

We have also produced mediastinal emphysema by injecting air subcutaneously or directly into the lung. At the close of an experiment on changes in bronchial caliber (Francis [25]) performed on a cat by forcing bismuth subcarbonate into the bronchial tree and stimulating the vagus nerve, large bubbles of air were observed in the posterior mediastinum. They had apparently resulted from the rupture of an emphysematous bleb.

Galliard [26] considered that interlobular, mediastinal and subcutaneous emphysema may follow senile pulmonary atrophy, tuberculous pneumonia and bronchopneumonia which complicate infectious diseases. The author also added that mediastinal emphysema may follow violent efforts during parturition and severe dyspnea due to cholera and reported such a case. The question can be raised as to whether the immediate dyspnea in some cases is not one of the causes rather than an effect of mediastinal emphysema.

The commonest cause of subcutaneous and mediastinal emphysema in children is the rupture of an alveolus and may occur in pneumonia, croup and pertussis. A case of mediastinal emphysema which developed in a child of 18 months during a fit of coughing, three days after the crisis of pneumonia, has been reported by Boehme.[27] The emphysema disappeared in four days and was attributed to a ruptured bronchus (?). Gehrt [28] reported four cases of subcutaneous emphysema in grip pneumonia associated with tracheal stenosis due to edema of the trachea.

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25. Francis, B. F.: Changes in the Size and Shape of the Bronchi Following Vagus Stimulation, to be published.

26. Galliard, L.: L'emphysème du médiastin, Bull. et mém. Soc. méd. d. hôp. de Paris **10**:199, 1893.

27. Boehme, Gustave F.: A Case of True Mediastinal Emphysema, M. Rec. **95**:1052 (June 21) 1919.

28. Gehrt, J.: Hautemphysem und Stenose bei Grippe, Deutsche med. Wchnschr. **46**:1052, 1920.

In two cases of pandemic influenza reported by Symmers [29] distended air vesicles near the apex of the lung had ruptured. The soft tissues in the supraclavicular spaces were crepitant with infiltrated air. In another instance the rupture had occurred near the root of the lung, and bullae could be demonstrated over the pericardium up the neck and extending down as far as the crests of the ilia. Chronic fibrinous bronchitis as a symptom of mediastinal compression has been suggested by Mulligan and Spencer.[30] They reported a case which concerned a boy, aged 7 years. The condition disappeared following roentgen treatment. The cause was thought to be pressure on the blood vessels of the lungs causing a "leakage" of fluid into the bronchial tree. Two patients who were operated on for carcinoma of the esophagus and who died of slow suffocation have been reported by Faure.[31] A drain had been used in both instances. The author wrote, "I could plainly see that a large quantity of air penetrated the mediastinum at each inspiration." Perforation of the esophagus by spicules of bone may be followed by mediastinal and subcutaneous emphysema. Pearce [32] published the report of a case which concerned a patient who apparently swallowed a spicule of bone. The patient died forty-eight hours after the onset of symptoms. Bilateral pneumothorax was present. Von Bokay [33] saw mediastinal emphysema develop only four times in 2,000 intubations in children. Baranger [34] reported a case of traumatic mediastinal emphysema. He treated the condition by making a transverse incision above the manubrium and by plunging his finger downward behind the sternum (Tiegel [35]). This act was followed by a rush of gas. Because he thought that the condition was due to a valvular pneumothorax, he made an incision into the pleura and, finding a tension pneumothorax on the right side, relieved it and the patient recovered.

Mueller [36] has shown that the heart's action also helps to spread the air in the mediastinum and that the coarse bubbling noises which are to be heard over the precordium are expressions of collections of air which

29. Symmers, D.: Pathologic Similarity Between Pneumonia of Bubonic Plague and of Pandemic Influenza, J. A. M. A. **71**:1482 (Nov. 2) 1918.

30. Mulligan, P. B., and Spencer, R. D.: Chronic Fibrinous Bronchitis as a Symptom of Mediastinal Compression, J. A. M. A. **82**:791 (March 8) 1924.

31. Faure, F.: The Surgery of the Posterior Mediastinum: Its Past and Future, Bull. Johns Hopkins Hosp. **16**:125, 1905.

32. Pearce, W. H.: An Unusual Case of Emphysema, Lancet **2**:221, 1886.

33. Von Bokay, cited by Gehrt (footnote 28).

34. Baranger, M.: Un cas d'emphysème médiastinal traumatique, Bull. et mém. Soc. nat. de chir. **52**:1243, 1926.

35. Tiegel: Ein einfaches Verfahren zur Bekampfung der Mediastinalemphysems, Zentralbl. f. Chir., March 25, 1911, p. 420.

36. Mueller, cited by Gehrt (footnote 28).

are compressed between the heart and wall of the chest. Lenormant [37] was of the opinion that the chief danger in mediastinal emphysema is circulatory. He considered that the extreme dyspnea, the feebleness of heart action, the smallness, frequency and irregularity of the pulse, the cyanosis of the face, the distention of the neck and the coldness of the nose and extremities all verify this fact. Subcutaneous emphysema, he stated, is secondary. He cited one case which followed an injury. He opened the thorax and found the lungs riding on an enormously distended mediastinum. The vena azygos was the size of a thumb, and the inferior vena cava the size of a child's arm. He attempted to aspirate the air (Tiegel), and also made multiple incisions but all to no avail. "De la rupture pulmonaire chez les enfants et de l'emphysème général qui l'a succèdé" was the title of a paper published by Ozanam [38] in 1854. The conclusions which he drew were as follows: All pulmonary conditions, all violent respiratory efforts, can cause a rupture of pulmonary tissue in the infant. Such a rupture is followed by internal and external emphysema. The external emphysema follows the cellular tissue and skin; the internal follows the bronchi and serous paths. Therapeusis consists in quieting respirations, rendering the patient insensible and evacuating the air by puncture with trocar.

Mediastinal emphysema as a complication of artificial pneumothorax occurred fifteen times in nine of sixty-three patients (Parfitt [39]). There were symptoms of discomfort under the sternum and in the neck, and slight pain beneath the sternum and in the neck. Crackling noises on swallowing or on moving the jaws could be heard by the patients as well as through the stethoscope. Parfitt noted that all symptoms in his patients disappeared in thirty-six hours. It would not seem unlikely that some of the reactions noted during pneumothorax treatment and previously attributed to other causes are perhaps due to slight degrees of mediastinal emphysema. This would apparently be more likely to occur when air collects on the mediastinal side of the lung, when the mediastinum is unstable and when the intrapleural pressure becomes positive. In the majority of instances, the lung itself is injured. Pick [40] reported the occurrence of mediastinal emphysema in a patient receiving pneumothorax treatment which resulted from the rupture of a tuberculous cavity. Some relief was obtained by puncturing cutaneous blebs. The

37. Lenormant, C.: Le traitement de l'emphysème médiastinal d'origine traumatique, Presse méd. **28**:286 (April 8) 1911.

38. Ozanam, C.: De la rupture pulmonaire chez les enfants et de l'emphysème général qui lui succède, Arch. gén de méd. **1**:31, 1854.

39. Parfitt, C. D., and Crombie, D. W.: Five Years Experience with Artificial Pneumothorax, Am. Rev. Tuberc. **3**:385, 1919.

40. Pick, E.: Ueber einen Fall von Haut und Mediastinalemphysem bei Lungentuberkulose, Wien. klin. Wchnschr. **38**:58 (May 7) 1925.

patient died two months later, and it is worthy of note that evidences of emphysema were demonstrable in the thickened pleura which was apparently not completely or solidly obliterated. Schill [41] has shown that mediastinal adhesions may also be loosed during pneumothorax treatment. Sercer and Peicic [10] treated a patient suffering from mediastinal emphysema which developed following a tracheotomy by expressing air from the tissues. Cyanosis and dyspnea were relieved. In another case due to a ruptured tuberculous cavity, the condition failed to respond to similar treatment and to the introduction of a trocar over the jugulum. Jehn [42] reported a case of mediastinal emphysema which followed fracture of the laryngeal box. Exposure of the jugulum, tracheotomy and the use of cardiac stimulants gave no relief. The patient died from a phlegmon of the mediastinum. Fracture of the thyroid cartilage and emphysema were also observed by Conwell.[43] Good results have apparently been obtained from the use of the Tiegel suction apparatus in some such instances of mediastinal emphysema. Wassermann [44] reported that mediastinal emphysema may simulate stenocardia, and Wiskovsky and Camrda [45] have reported the occurrence of mediastinal and subcutaneous emphysema in a patient after the inhalation of a bean into the right bronchus. Recovery occurred after the extraction of the foreign body through a bronchoscope.

Alexander and Follett [46] have discussed various types of emphysema. They made particular reference to that form which occurs in children and which is due to rupture of a congenitally or otherwise weakened alveolus. These authors have classified emphysema into three broad groups: (*a*) congenital, which is rare, (*b*) emphysema in infants due to a variety of causes which may be responsible for the rupturing of an alveolus, and (*c*) the traumatic group. Mediastinal and subcutaneous emphysema may be a consequence of congenital cystic lung (Box [47]).

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41. Schill, E.: Pneumothorax Studien. Mediastinal Emphysem als Komplikation des kunstlichen Pneumothorax, Beitr. z. Klin. d. Tuberk. **65**:505, 1927.

42. Jehn, W.: Klinisches und experimentelles ueber das Mediastinalemphysems, Arch. f. klin. Chir. **38**:195, 1925; Ein Beitrag zur Klinik und Pathologie des Mediastinalemphysems, Deutsche Ztschr. f. Chir. **140**:398, 1917; Das Mediastinalemphysem, Ztschr. f. Chir. **48**:1619, 1921.

43. Conwell, H. E.: Fracture of the Thyroid Cartilage, J. Bone & Joint Surg. **11**:123 (Jan.) 1920.

44. Wassermann, S.: Das Mediastinale Emphysem, Wien. klin. Wchnschr. **6**: 122, 1920.

45. Wiskovsky, B., and Camrda, I.: Mediastinal and Subcutaneous Emphysema After Inhalation of a Bean into the Right Bronchus; Recovery After Extraction of a Foreign Body Through Peroral Bronchoscopy, Bratisl. lekár. listy **11**:195, 1922-1923.

46. Alexander, M. E., and Follett, E. C.: Subcutaneous Emphysema, J. A. M. A. **72**:930 (March 29) 1919.

47. Box: Bronchiectasis in Childhood with Some Observations on the Condition Known as Honeycomb Lung, Lancet **1**:16, 1907.

Achard [48] was able to produce mediastinal emphysema in dogs by a variety of methods. He injected air subcutaneously over the thorax and elsewhere, and was able to produce mediastinal emphysema. We repeated this experiment in one instance (in a rabbit) and also obtained a positive result.

Generalized interstitial emphysema and spontaneous pneumothorax were observed as complications of bronchopneumonia following influenza by Berkley and Coffen [49] in 11 out of 1,701 instances. There were five deaths. This complication occurred in the more severely ill patients and often apparently followed a sudden severe paroxysm of coughing. The emphysema was first noted in the soft tissues of the episternal notch. All patients complained of choking sensations. Pneumothorax was observed twice.

Kelman [50] examined twenty patients who died of influenza, and at necropsy found marked vesicular and interstitial emphysema. The former was most marked, however, at the margins of the lungs. Interstitial emphysema involved mainly the anterior and posterior mediastina, which included the pericardium and pericardial fat. It could also be observed in the perirenal tissue. She produced experimental emphysema by inflating the lungs of dead rabbits with air by means of a bicycle pump.

Rapid and extensive emphysema with severe collapse caused by the passage of a cart wheel over the thorax, in which marked relief was obtained at once by multiple punctures of the skin, was reported by Bisshopp.[51] Nine or ten punctures were made in the neck, back, cheek and dorsal region with a small knife, "and when the air rushed out it hissed and blew out the flame of a wax light." Emphysema of the scrotum was the last to disappear. Surgical emphysema, which resulted from a bayonet wound of the buttock which punctured the lung, was noted by Hayward.[52]

Silvester [53] was of the opinion that the production of subcutaneous emphysema should prove an excellent means of saving the life of a

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48. Achard, C.: Étude experimentelle de l'emphysème du médiastin, Bull. Acad. de méd. **80**:609, 1918.

49. Berkley, Hugh K., and Coffen, T. Homer: Generalized Interstitial Emphysema and Spontaneous Pneumothorax as Complications of Bronchopneumonia, J. A. M. A. **72**:535 (Feb. 22) 1919.

50. Kelman, S. R.: Experimental Emphysema, Arch. Int. Med. **24**:332 (Sept.) 1919.

51. Bisshopp: Extensive Emphysema with Severe Collapse from Passage of a Cartwheel Over the Thorax Treated at Once with Marked Relief with Multiple Punctures of the Skin, Brit. M. J. **1**:163, 1884.

52. Hayward, J. D.: Bayonet Wound of Buttock: Lung Punctured; Surgical Emphysema, Lancet, August 11, p. 199.

53. Silvester, H. B.: On Life-Saving from Drowning by Self-Inflation, Lancet **1**:11 (Jan. 31) 1885.

person who has almost drowned. He has given an interesting account of the air chambers of certain birds and swim bladders of fish. He demonstrated how a body could actually be blown by forcing air under the skin of the wrist. For the average person he devised a simple method "which could be accomplished without the employment of any apparatus and in fact which might be performed without assistance in a moment, under the most adverse circumstances and by the most ignorant, if once instructed in it and without danger or pain, and suitable alike for the roughest sailor or the most delicate female." It was required that a sharp instrument be introduced opposite the first molar tooth and cheek down to the skin of the neck. On expiration, it would be possible to blow up the neck and chest to the nipples. In a communication to court, he wrote that in the absence of a sharp instrument the mucous membrane of the side of the mouth could be affected by the person's own teeth.

Entrance of air into the mediastinum during operations on the base of the neck has also been reported by Buford.[54] He has recorded two cases. One patient complained of extreme dyspnea, precordial fulness and pain and was quite cyanosed. Air hunger became great, and finally subcutaneous emphysema developed over the side of the neck and chest. Marked relief and improvement followed venesection.

That perineal emphysema may spread to the upper parts of the body was noted by Erichsen[55] who recorded its occurrence following puncture of the urinary bladder through the rectum for retention (see also Tatum).[56]

The relationship of subcutaneous emphysema to abdominal operations has been discussed by Heil,[57] Madlener,[58] Meinert[59] and von Graefe.[60]

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54. Buford, Coleman G.: Entrance of Air into Mediastinum During Operations on Base of Neck, Surg. Gynec. Obst. **26**:540 (May) 1918.

55. Erichsen: Perineal Emphysema Spreading to the Upper Parts of the Body from Puncture of the Bladder Through the Rectum for Retention, Lancet **1**:89, 1860.

56. Tatum: Perineal Emphysema Spreading to the Upper Parts of the Body, Lancet **1**:90, 1860.

57. Heil, K.: Ueber die Entstehung des Hautemphysems nach Laparotomiem, Arch. f. Gynäk. **435**:52, 1896; Ein weiteren Beitrag zur Entstehung des Hautemphysems nach Laparotomiem, München. med. Wchnschr. **35**:1208, 1900.

58. Madlener, M.: Das Haut Emphysem nach Laparotomiem, Monatschr. f. Geburtsh. u. Gynäk. **13**:305, 1901.

59. Meinert: Ueber emphysem der Bauchdecken nach Laparotomiem, Zentralbl. f. Gynäk. **50**:1328, 1895.

60. Von Graefe: Ueber locales traumatisches Hautemphysems nach Laparotomien, München. med. Wchnschr. **42**:823 (Oct. 16) 1894.

In 1899, Klots [61] reviewed the literature concerning subcutaneous emphysema of the mother which developed during childbirth. He collected forty instances. Thirty-one occurred in primiparas. Emphysema was first noted in the neck over the clavicle. It developed during the period of expulsion when the intra-abdominal pressure becomes markedly increased; the diaphragm immobilized and when attempts at forced inspiration were made with the glottis closed then emphysema interstitiale pulmonum must of necessity develop. Air will escape between the parenchyma of the lung and pleura to the anterior mediastinum. Klots noted that Decadas' patient had pleuritis, Eisler's had previously had hemoptysis and one patient (Filippow) eclampsia. Nearly all the women so affected were robust. The abnormal local conditions were too large a head, contracted pelves and rigidity of the soft parts. The prognosis in general was considered to be good and resorption rapid. No treatment was suggested. Klots stated that when subcutaneous emphysema develops labor should be ended. The condition, he feels, is frequently overlooked.

The relation of mediastinal and subcutaneous emphysema to pneumothorax has recently received consideration at the hands of Kovacs.[62]

Le Soudier [63] has reported the association of subcutaneous emphysema with diphtheria. Three similar occurrences had apparently been previously reported.

Morgan,[64] in 1826, discussed the development of subcutaneous emphysema into the loose tissue of the eyelid which followed a fracture of the os frontale; the air came from the frontal sinuses. The principle involved is obviously the same throughout the body.

General emphysema may follow the rupture of a viscus. Such a case which followed rupture of the stomach has been described by Newman.[65]

It is important, as von Braman [66] pointed out, to differentiate between an injury to the pleura costalis and the pleura pulmonalis. Subcutaneous emphysema which develops after an injury of the rib implies that the

61. Klots, S.: Emphysema subcutaneum während des geburactes Entstanden, Ztschr. f. Geburtsh. u. Gynäk. **41**:357, 1899.

62. Kovacs, F.: Ueber den Emphysempneumothorax, Wien. klin. Wchnschr., vol. 21, p. 716.

63. Le Soudier: Un cas d'emphysème sous-cutane dans la diphtérie, Arch. d. méd. d. enf., 1917, July, 20, p. 360.

64. Morgan: Fracture of the Os Frontis into the Frontal Sinus with Extravasation of Air into the Cellular Membrane of the Eyelid, Lancet **10**:31, 1826.

65. Newman: A Case of General Emphysema Following Rupture of the Stomach, Lancet **2**:728, 1868.

66. Von Braman: Ueber die Behandlung des nach Lungenverletzungen auftretended allgemiener Korperemphysems, Verhandl. d. deutsch. Gesellsch. f. Chir., 1893, p. 114.

pleura pulmonalis is injured—in other words, that there has been injury to the lung tissue. No matter how small, a pneumothorax must of necessity be present. Even a lateral view with the affected side up may, however, fail to disclose its presence. The lung, if it is injured when a rib is fractured, is usually injured during inspiration. Von Braman has treated such patients by closed drainage. Air which escapes into the thorax is thus expelled. In discussing von Braman's paper, Konig rightly pointed out that blood in many instances sears over the wound. The early development of pleural adhesions would act in the same way.

TREATMENT OF MEDIASTINAL AND SUBCUTANEOUS EMPHYSEMA

It would appear that the treatment of mediastinal emphysema must vary with the cause, severity and progress of the condition. If there is an associated tension pneumothorax or an increased intrapleural pressure, they should be relieved, the former, if necessary, by an open operation; the latter is done by use of the pneumothorax apparatus. If the mediastinal emphysema develops after strumectomy, a cold wet pack placed substernally may prevent the further entrance of air into the mediastinum. Teigel's suction cup or a needle placed in the jugulum and attached to a pneumothorax apparatus may be of help. Subcutaneous emphysema usually responds to incision. If cyanosis is extreme, venesection might be suggested. The patient should be kept quiet as cough may expel more air from the lung. Closed drainage might also be considered. Pain should be alleviated, as the splinting of the thorax may favor the progress of the condition.

SUMMARY

Experiences concerning some of the consequences of variations in mediastinal pressure have been here recorded.

Particular attention has been paid to mediastinal and subcutaneous emphysema.

Variations in the arterial, venous and intrapleural pressures and respirations which resulted from changes in the size, shape and contour of the anterior and posterior mediastina have been noted.

Practically all of the forty experiments were performed on rabbits, because the mediastina of rabbits are best fitted for such experiments.

Experiments with a rubber balloon in the mediastinum illustrated the effects of sudden confined increase in mediastinal pressure, and how these effects can be made to disappear by reducing the pressure. The consequences were local and varied directly with the extent to which the balloon had been inflated and the position which it occupied in the mediastinum.

The initial change in the blood pressure following the injection of air into the rubber balloon which was placed in the mediastinum was always a fall in blood pressure.

The anterior mediastinum was considered to lie in front of the root of the lung, the posterior mediastinum behind the root of the lung.

It is much easier for compression of the large blood vessels to occur than of the trachea or bronchi.

Some of the consequences of increased mediastinal pressure are pulmonary emphysema which may be partly hyperventilation or hypoventilation of the lungs, stagnation of blood in the lungs, hindered heart action, edema of the lungs and the development of fluid in the pericardial cavity.

Edema of the tracheobronchial mucous membrane may also be a consequence.

The position and size of the opening which is allowing air to escape into the mediastinum is of the same import as it has been shown to be in open pneumothorax by Graham. The presence of a tension pneumothorax or of an uncomplicated unilateral or bilateral pneumothorax as consequences of mediastinal emphysema must always be excluded.

Mediastinal emphysema was produced directly by various means, including the direct injection of air into the mediastinum and by producing tracheal fistulas.

The courses which air may take in the production of mediastinal and subcutaneous emphysema have been pointed out. In so doing the air follows with predilection the normal fascial planes, particularly the sheaths which surround blood vessels. It may also extend retroperitoneally, outline the kidneys and compress the renal vessels.

Large amounts of blood can become stagnant in the lung without producing marked pressure changes in the circulation.

The direct injection of frequent small amounts of air into the mediastinum caused a fall in blood pressure and an increase in respiratory rate. The blood pressure soon returned to normal if the injections were not repeated too frequently. Only gradual rises and falls in venous pressure were observed. These rises and falls in venous pressure followed no definite rule. Transitory terminal rises concomitant with the fall in arterial pressure could be observed.

The effects of the injection of mixtures of paraffin and iodized oil which solidified have also been recorded.

Some remarks concerning treatment of the condition have been made. With regard to the treatment, it can be said that the necessity of ruling out the presence of a tension pneumothorax or of a simple pneumothorax is of extreme importance.

9. COMPARISON OF IODIZED OIL AND BROMINIZED OIL *

JACOB J. SINGER, M.D.
AND
BYRON F. FRANCIS, M.D.
ST. LOUIS

The use of a brominized oil as a contrast medium in roentgenology has been suggested in order to overcome certain dangers which are supposed to be inherent in iodized oils. Several manufacturers have made preparations of brominized oil and have put them out under various names. Our experience with this type of oil has been limited but sufficient to give us certain impressions.

In view of the fact that other investigators have made statements that iodized oil is likely to produce an aggravation of symptoms and signs in tuberculous patients, we thought it advisable to review our statistics to determine whether we could substantiate this. During the routine work in our chest service, 277 patients have received intratracheal injections of iodized oil (lipiodol). Thirty-five of these were cases of chronic pulmonary tuberculosis. Three patients, none of them tuberculous, developed definite symptoms and signs of iodism, but all of them had swallowed a considerable quantity of the oil which had been introduced. We have not observed any unusual after-effect in any of the tuberculous patients who were given injections. A few patients have been given injections with brominized oil, and none of these has shown any bad effects.

If one refers to Archibald and Brown's [1] article on "The Dangers of Introducing Iodized Oil into the Tracheo-Bronchial System," it will be noted that the iodized oil was injected into tuberculous patients through a bronchoscope or intratracheal catheter. When one considers that many tuberculous patients develop a rise in temperature, an increase in cough and other symptoms in addition to increased physical signs following muscular effort, it can readily be seen that the procedures which were used rather than the oil itself in many cases might explain the reaction.

In this clinic the method of aspiration described by one of us (J. J. S.[2]) has been employed. This method causes the patient a minimum of

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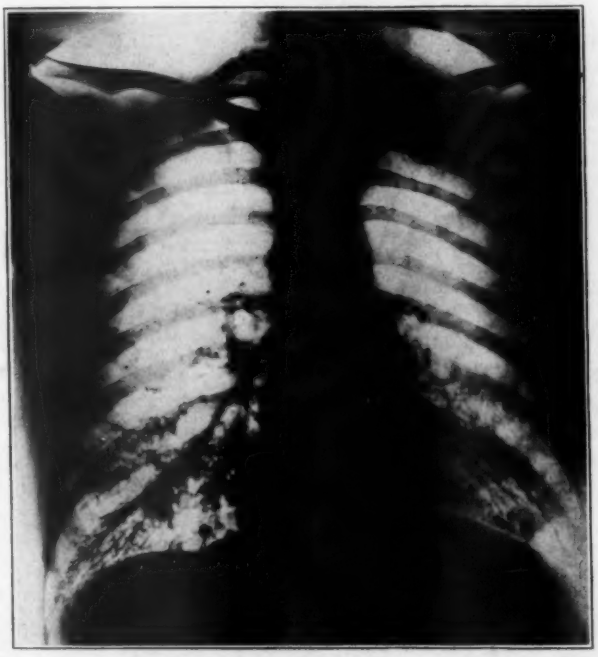
* From the Department of Medicine, Washington University School of Medicine, and Barnes Hospital.

1. Archibald, E. W., and Brown, A. L.: Dangers of Introducing Iodized Oil into the Tracheobronchial System, J. A. M. A. **88**:1310 (April 23) 1927.

2. Singer, J. J.: A Simple Method of Introducing Iodized Oil into the Lungs, J. A. M. A. **87**:1298 (Oct. 16) 1926.

muscular exertion. We feel that this has been a factor accounting for the lack of bad effects from the administration of the oil.

Ballon [3] has shown that the injection of iodized oil into the lung of a rabbit is not followed by any inflammatory reaction that can be demonstrated either macroscopically or microscopically. However, rabbits with pulmonary tuberculosis, made more acutely ill by various means, had their death hastened by the endobronchial injection of oil, not, however, because of an extension of the process but rather because of an aggravation or intensification of the underlying condition. So far as



Roentgenogram of the chest of a woman, aged 23, with bilateral bronchiectasis. By the aspiration method 20 cc. of iodized oil was first introduced into the right side; then the patient was caused to lean toward the left and 20 cc. of brominized oil was introduced into the left lung. It may be readily seen that the density of the bronchial outlines is much less on the left side where the brominized oil entered.

we know, similar experimental work has not been undertaken with a brominized oil. Putnam [4] studied experimentally the irritating effect of brominized oil by introducing it into the anterior chamber of the eye,

3. Ballon, H. C.: Lipiodal bei Lungentuberkulose: experimentelle Klinische und pathologische Studie, Frankfurt. Ztschr. f. Path. **36**:207, 1928.

4. Putnam, Jackson: Some Brominized Oils for Radiographic Use, J. A. M. A. **87**:1102 (Oct. 2) 1926.

using the resulting increase in cell count of the vitreous humor as an index of the severity of the reaction. Dyroft,[5] Rad [6] and Iglauer [7] have used a brominized oil clinically in the lungs, especially in cases of tuberculosis. Iglauer stated the belief that a brominized oil causes less reaction than iodized oil in pulmonary tuberculosis. However, his conclusions are based on two series of cases which we believe cannot be accurately enough compared.

Another factor to be considered in comparing iodized oil with brominized oil is the fact admitted by Iglauer, Rad and Dyroft that the density of a shadow cast by an oil containing bromine is less than that of an oil containing iodine. This, of course, is a characteristic which varies with the atomic weights of the elements. Since it is often desirable to outline structures within dense shadows cast by the x-rays, it is readily seen that it is advantageous to have a contrast medium which is as opaque as possible. The iodized oils have been satisfactory as a contrast medium.

It would be an advantage if the concentration of bromine could be made great enough in an oil of suitable viscosity so that it could be used in cases in which iodine is contraindicated.

Our experience with iodized oil in patients with pulmonary tuberculosis up to the present time does not contraindicate its further use in such conditions.

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5. Dyroft, Rudolf: "Contrastol" ein neues Kontrastmittel fur die Darstellung engkolibriger Hohlraume, Deutsche med. Wchnschr. **52**:397 (March 5) 1926.

6. Rad, Alexander: Die Fuelung des Bronchialbaumes mit Jodolen und Bromipin, Wien. klin. Wchnschr. **39**:1011, 1926.

7. Iglauer, Samuel, and Kuhn, Hugh: Advantages of Brominizied Oil in Bronchography in Tuberculous Patients, J. A. M. A. **90**:1278 (April 21) 1928.

10. EFFECTS OF PRESSURE ON THE HEART, WITH REFERENCE TO THE ADVISABILITY OF DECOMPRESSION OF GREATLY ENLARGED HEARTS

EXPERIMENTAL STUDY *

DUFF S. ALLEN, M.D.
AND
EVARTS A. GRAHAM, M.D.
ST. LOUIS

This is an experimental study of the effects of pressure on the heart. Its purpose is to determine the feasibility of decompression of a massively hypertrophied heart in the human being. It would seem that in cases in which the heart is greatly enlarged, there might be an abnormally high pressure on the heart because it is encased in the non-yielding, bony thoracic cage. In considering this question, we desire to focus attention particularly on the question of the harm produced on the heart muscle by pressure exerted on it by the wall of the chest because of the massive enlargement of the organ. We are here not considering the questions of giving relief by decortication of a thickened pericardium (Delorme) or by allowing the heart to contract against a yielding instead of a rigid structure, as is proposed in the cardiolysis of Brauer in cases of chronic mediastinopericarditis. There are many cases of massive enlargement of the heart in which there are no clinical signs of an adhesive mediastinopericarditis and in which also decortication itself would not be indicated because the pericardium is neither thickened nor adherent.

The experiments were made on normal hearts of dogs and consisted of applying pressure continuously, for varying periods of time, to the ventricles, to the auricles or to both. Blood pressures were recorded from the femoral artery at the same time. The experiments recorded here are acute experiments, and the changes in blood pressure are those which occur soon after the external pressure on the heart is altered.

CLINICAL ASPECTS

Decompression of an enlarged heart was advocated by Alexander Morison,[1] of Edinburgh, in 1907 and was performed on a patient of

* From the Department of Surgery, Washington University School of Medicine and Barnes Hospital.

1. Morison, A.: On Thoracostomy in Heart Disease, Lancet **2**:7 (July 4) 1908; Further Report on a Case of Thoracostomy for Heart Disease, ibid. **2**:1494 (Nov. 20) 1909.

his by E. C. Stabb, with marked improvement. He recommended the removal of ribs, costal cartilages and a portion of the sternum for relief from embarrassment to the hypertrophied heart. He considered this for (1) the relief of increased intrathoracic pressure due to the large heart and (2) to prevent undue stimulation of the heart from continued thrusts or blows against the ribs. It seems to us that he might have added, also, that anemia of the heart muscle and interference with diastole would probably result from an increase in the extracardiac pressure.

Bewley [2] reported a case of decompression for hypertrophy of the heart in which sections of the third, fourth and fifth ribs were removed along with the lower half of the sternum. He gave the indication for such decompression as follows: "To sum up, when we find that the ribs or sternum, or both, are distinctly moved up by each systole of the heart, I hold that this movement may be looked upon as the heart's prayer for more room."

Lenormant and Merle D'Aubigne [3] collected fourteen cases in which the operation for decompression of the enlarged heart had been carried out. Of these fourteen patients five, or 35 per cent, showed definite and lasting improvement. These authors considered such a percentage remarkable in view of the original condition of the patients on whom the operations had been carried out. It is not certain, however, that in all these cases the operation was performed merely for decompression. It seems more probable that in many cases the operation was indicated by the presence of a chronic adhesive mediastinopericarditis. Such cases do not properly fall within the group under consideration here.

PREVIOUS INVESTIGATIONS

Investigations have been made in which the normal pressure on the exterior of the heart has been altered. Most of these investigations in the past have been concerned with the changes incident to removal of the pericardium. It is thought that this produces a decrease in support and hence a decrease in the normal external pressure on the heart. Kuno [4] found that opening of the pericardium causes a fall of venous pressure, a rise of arterial pressure and an increase of output. Beck and Moore [5] found little change in the function of the heart in animals from which the pericardium had been removed.

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2. Bewley, H. T.: A Clinical Lecture on Cardiolysis, Brit. M. J. **1**:915, 1910.

3. Lenormant, C., and D'Aubigne, R. M.: La thoracectomie précordiale dans les symphyses et certaines hypertrophies cardiaques, J. de chir. **31**:161, 1928.

4. Kuno, Y.: The Significance of the Pericardium, J. Physiol. **50**:1, 1915-1916.

5. Beck, C. S., and Moore, R. L.: The Significance of the Pericardium in Relation to Surgery of the Heart, Arch. Surg. **11**:550 (Oct.) 1925.

The changes in the circulation have been studied in normal animals in which the intrapericardial pressure has been raised above the normal. This increase was produced by the introduction of fluids and gases within the pericardium. Rose [6] first termed this "tamponade."

In these tamponade experiments, marked changes in the circulation and in the respirations are noted. As the intrapericardial pressure was raised the systemic blood pressures fell, the pulmonary venous pressures rose and the respirations became deeper and slower.

EXPERIMENTAL WORK

We wish to point out that the present experiments with increased extracardiac pressures are not studies in heart tamponade. The present study is concerned with pressures applied directly to the ventricles or to the auricles. In tamponade experiments, equal pressures are applied simultaneously to the ventricles, to the auricles and to the thin-walled veins (the venae cavae and the pulmonary veins) entering the pericardium. The effects of tamponade due to fluids are mainly those incident to compression of these veins. It is probable that no such compression occurs in the veins entering the pericardium in cases of hypertrophy of the heart. It is logical to think that in these cases the increase in extracardiac pressure is most marked on the ventricles and auricles. Our experiments, therefore, more closely resemble the state of affairs in the hypertrophied human heart which is gripped within the bony thorax.

Method.—Normal adult dogs were used in these experiments. They were fully anesthetized with ether; the cavity of the left side of the chest was opened widely after artificial respiration had been instituted with the Erlanger-Gesell apparatus. Intermittent positive intratracheal pressure was obtained by this method. This closely resembles the normal respiratory cycle.

After the pericardium had been exposed, the femoral artery was exposed, a cannula was inserted and this attached to a mercury manometer or to the more sensitive Hurthle manometer. The changes in blood pressure were recorded on a drum of smoked, glazed paper.

The external pressure on the heart was increased above the normal by weights laid directly on the intact pericardium over the ventricles, by pressure applied to the ventricles or the auricles by the fingers or by interrupted sutures accurately placed in the intact pericardium in such a manner as to apply pressure to the ventricles or to the auricles when the sutures were tightened.

The animals were given a lethal amount of ether at the end of the experiment.

Analysis.—Figure 1 shows the effect of moderate compression of the central portion of the ventricles. In this instance, care was used to prevent the heart from slipping upward and thus compressing the pedicle of the heart.

6. Rose, E.: Herz Tamponade, Deutsche Ztschr. f. Chir. **20**:329, 1884.

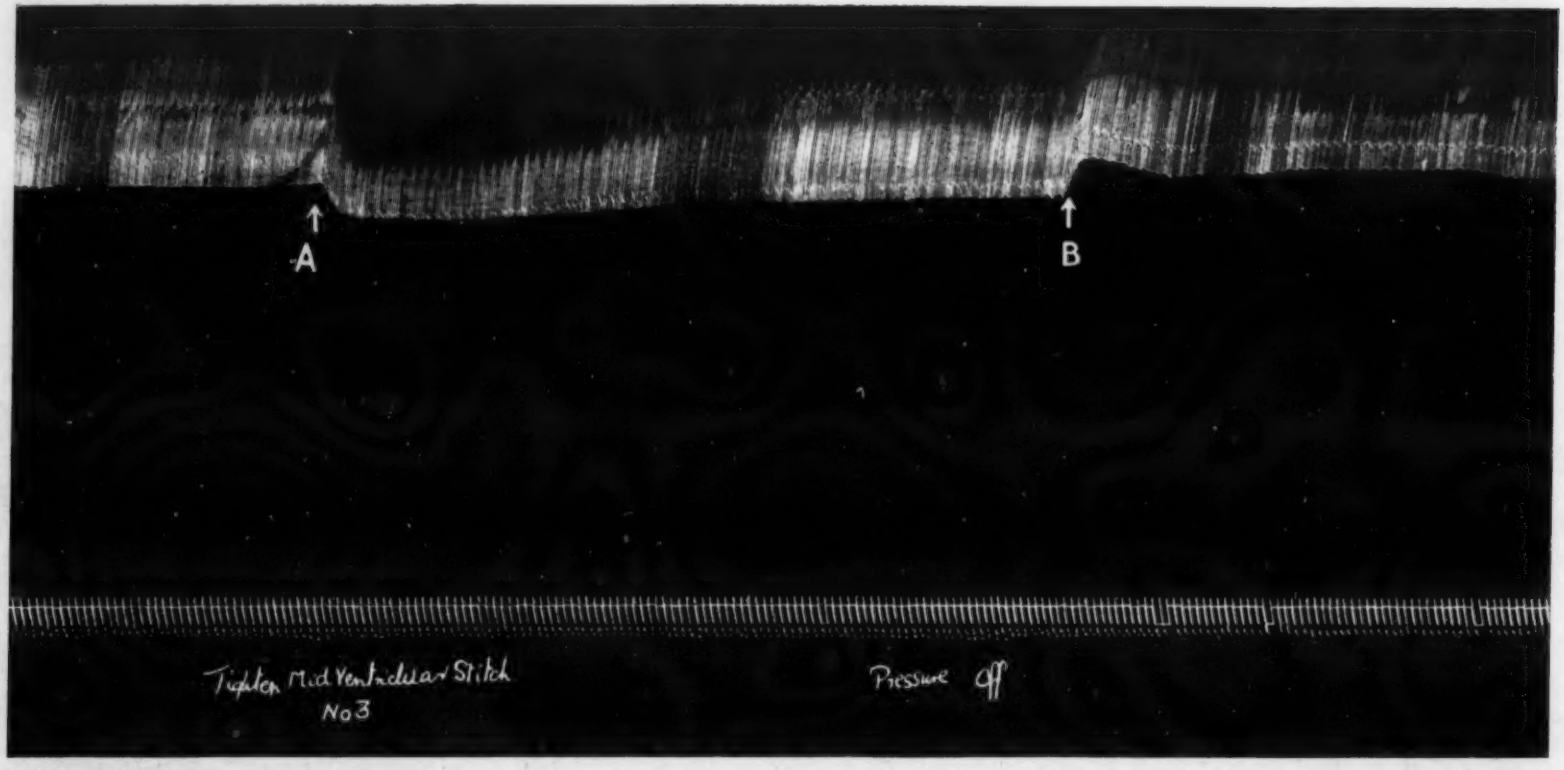

Fig. 1.—Changes in the systemic blood pressure during sustained pressure on the ventricles. There is a fall in blood pressure and a fall in the pulse pressure. The pulse pressure shows a tendency to approach the normal due to the compensatory activity of the arterial system. On sudden release of the pressure on the ventricles the diastolic pressure rises above the normal since the compensatory mechanism is not released suddenly. The pressure is applied at point *A* and released at point *B*.

The tracing shows the consequent changes in the pulse pressure and in the blood pressure within the femoral artery. Immediately on increase of the extracardiac pressure in the midportion of the ventricles at point *A*, there is a marked fall of the diastolic pressure, a more marked fall of the systolic pressure and, as a result, a lessening of the pulse pressure. Then follows a rather rapid rise in the systolic pressure. This is a manifestation of compensation in the circulatory system. The diastolic pressure remains low.

On release of the pressure on the ventricles at point *B*, the systolic pressure immediately rises above the normal. This, we believe, indicates the compensatory mechanism of the arterial system which aids in maintaining the normal blood pressure. When the heart is suddenly restored to normal conditions, this acting compensatory mechanism of the arterial system does not release itself so suddenly, and hence the diastolic pressure rises above the normal. The systolic pressure returns to normal, however, within a few minutes. There is a similar rise in the diastolic pressure, but the increase above the normal is not so great as with the systolic pressure. The pulse pressure is increased as a result of this inequality.

Figure 2 is a tracing made with the rather sensitive Hurthle manometer. It was made in the same fashion as was the tracing shown in figure 1. The upper pointer indicates the pulse pressure, the diastolic and the systolic pressure. The upstroke is due to systolic pressure. The parallel lines show the calibration for the manometer in millimeters of mercury. The time marked is in seconds.

Four interrupted stitches were placed in the intact pericardium in such manner that when they were tightened pressure was brought to bear on the ventricles of the heart. This was done, at point *A*, with results similar to those shown in the tracing in figure 1.

The second and third pronounced falls in the blood pressure, at points *B* and *C*, were produced by squeezing the ventricles tightly with the fingers with such marked compression that the pulse pressure falls very low, as do the diastolic and systolic pressures.

The fourth disturbance in the blood pressure, as shown on the tracing at point *D*, is due to marked compression of the auricles with the fingers. It shows disturbances in the systemic circulation similar to those produced by compression of the ventricles.

Figure 3 is a tracing made by the sluggish mercury manometer as it records the blood pressures in the femoral artery. It shows the comparative effects on the systemic pressure of hammering the ventricles with a hammer and sustained pressure on them produced by the fingers.

The first irregularities shown in the tracing between points *A* and *B* are due to extrasystoles induced by hammering the ventricles repeatedly with a hammer. Sharp, forceful blows were dealt the ventricles at inter-

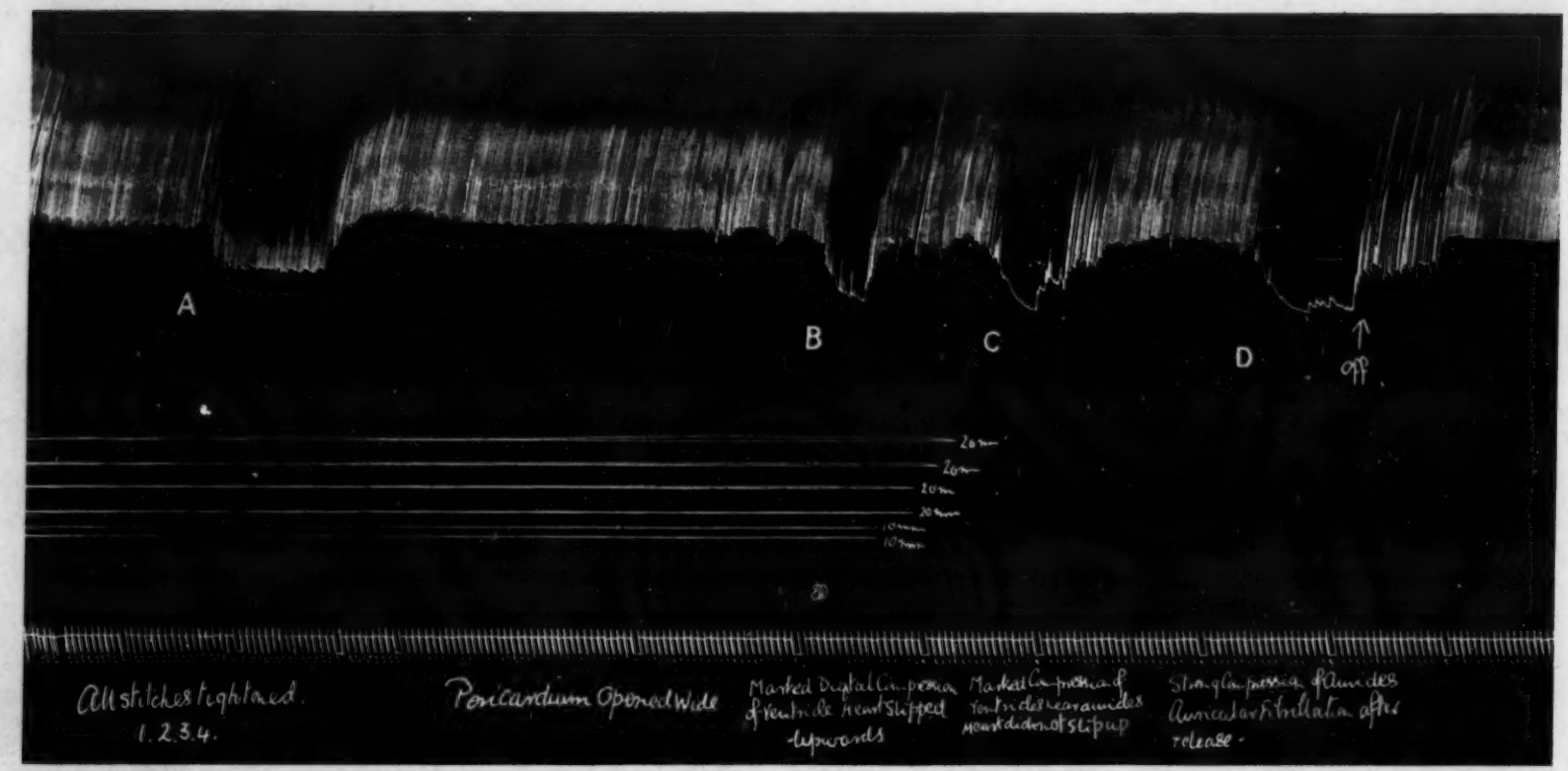

Fig. 2.—Result of moderate compression of the ventricles at point *A*. At point *B* the ventricles are strongly compressed with the fingers. The same marked compression was applied at point *C* and the auricles were compressed at point *D*.

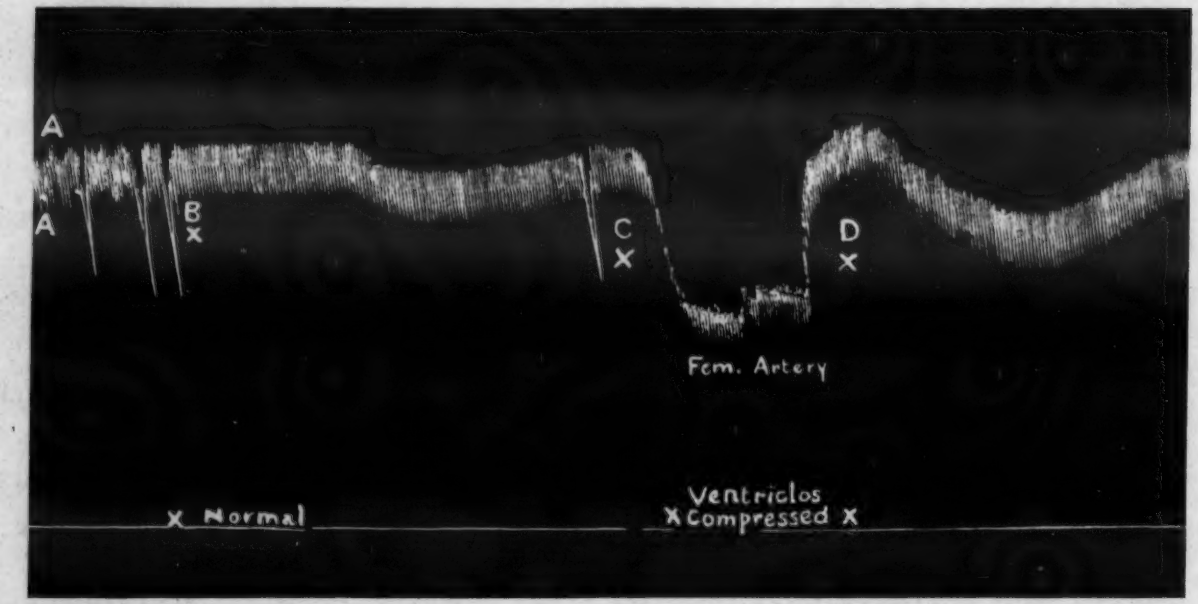

Fig. 3.—Section *A-B* shows the effect of hammering the ventricles with a hammer. The mean blood pressure is undisturbed, but there are numerous extrasystoles. Section *B-C* is the normal blood pressure. At *C* the ventricles were compressed, and at *D* the pressure was released. Sustained increased extracardiac pressure produces more marked changes in the blood pressure than nonsustained increased pressure.

vals not exceeding one per second nor less than one per two seconds. The tracing shows that the mean arterial pressure is unchanged by such procedures. The entire record is not shown in the figure here, but the terminal portion which is shown, is representative of the whole. Sometimes such hammering will set the ventricles into fibrillation. Unless this occurs, there seems to be but little effect on the mean arterial pressures in the systemic circulation.

The second disturbance shown in the tracing at point *C* is a marked fall in the mean pressure accompanied by a fall in the pulse pressure. This alarming fall in the systemic arterial pressure was occasioned by moderate compression of the ventricles with the fingers.

The tracing shows most clearly that a sustained increase of the extracardiac pressure applied to the ventricles produces a more marked fall in the mean blood pressure than repeated nonsustained increases.

This tracing indicates, therefore, that repeated thrusts of the enlarged human heart against the wall of the chest might be of little consequence. It also indicates that a heart which has become enlarged sufficiently to be impinged on continuously by the rigid thoracic wall might suffer impairment of its efficiency.

COMMENT

More than 100 observations were made on the hearts of 12 dogs. A careful analysis of the records shows that whenever the extracardiac pressure is increased, and maintained for a considerable period of time, there is a decrease in the efficiency of the heart. This is manifest by a fall in the mean blood pressure in the systemic circulation and a decrease in the pulse pressure.

This is soon compensated for, in the normal animals, by changes in the arterial system which are to maintain the normal blood pressures.

The heart remains embarrassed by the sustained increase in extracardiac pressure.

It is logical to infer, therefore, that the human heart is similarly less efficient when it is enlarged sufficiently to be pressed on continuously by the bony framework of the thorax. Decompression of such an enlarged heart should relieve the increased extracardiac pressure and would be expected to increase the efficiency of the heart.

Two patients with greatly enlarged and chronically decompensated hearts were operated on for the purpose of affording a decompression. In neither case was there any clinical evidence of an adhesive mediastinopericarditis. Both patients showed marked temporary improvement, but both ultimately succumbed. In one case, however, death was due not to the cardiac condition but to an acute pneumonia which occurred three months after the operation. Even during the pneumonia there

were no edema or other signs of cardiac decompensation. It is interesting also that in this case, in which the patient received the greater benefit, the pericardium was opened and found not to be thickened. Decortication, therefore, was not indicated. The beneficial result seems to have been due entirely to the decompression. These cases, together with the descriptions of the operations performed on them, have been reported elsewhere by one of us.[7]

7. Graham, E. A.: Decompression of the Heart, Ann. Surg. **90**:817 (Nov.) 1929.

11. CYTOLOGY OF SEROUS EFFUSIONS, WITH SPECIAL REFERENCE TO TUMOR CELLS*

ALFRED GOLDMAN, M.D.
ST. LOUIS

The study of the cellular structure of effusions is a valuable laboratory procedure. The most satisfactory method of study is that devised by Mandlebaum.[1] The fluid is placed in a large Erlenmeyer flask and allowed to stand over night in the icebox. The supernatant fluid is decanted and the sediment poured in a large 50 cc. centrifuge tube and centrifugated for at least twenty minutes at a moderate speed. The supernatant fluid is again decanted and the sediment hardened with a diluted solution of formaldehyde, U. S. P. (1:10) or Zenker's fluid for twenty-four hours. The fixed sediment is then treated as ordinary tissue by running through alcohols, embedding in paraffin and staining with hematoxylin eosin. The tissue is cut from above down so as to include all the cellular elements.

This report is based on the study of fifty effusions prepared by this method from serous fluids in cases of malignant, cardiac and tuberculous disease. Incidentally, the specific gravity was noted in all fluids.

MALIGNANT EFFUSIONS

There were twenty cases of malignant disease in this series proved by autopsy, biopsy or a palpable mass, with gross characteristics of a malignant tumor. Effusions from these cases were studied with particular reference to the presence or absence of tumor cells. Zemansky[2] pointed out that in his series studied by Mandlebaum's method 60 per cent of fifty-five cases of carcinoma showed tumor cells in the effusions. In this smaller series, 80 per cent of the effusions showed cells which were interpreted as being malignant. A positive diagnosis of tumor cells may be made with the highest degree of accuracy. A negative diagnosis does not, of course, rule out a malignant condition. Obviously, there must be contact between the tumor and the fluid before tumor cells are "shed."

Tumor cells, as has been pointed out by Zemansky and others, appear in two main forms: (*a*) fragments of tumor tissue often showing glandular or pseudoglandular arrangements or clumps of tumor cells, and (*b*) isolated tumor cells, the characteristics of which will be mentioned later.

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* From the Department of Medicine, Washington University Medical School and Barnes Hospital.

1. Mandlebaum, F. S.: Proc. New York Path. Soc., 1900, p. 178.
2. Zemansky, A. P.: Am. J. M. Sc. **175**:673, 1928.

The first type is easy to diagnose and predominated in this series (thirteen cases). The cell clumps stand out as large deep-staining cells amid various types of blood cells and mesothelial cells (fig. 1). Occasionally the tumor fragments may be seen almost exclusively at the bottom of the centrifugate.

It is in those cases in which individual tumor cells occur that one may have difficulty in making a diagnosis. There were three such cases. Criteria for diagnosis here are large atypical deep-staining cells,

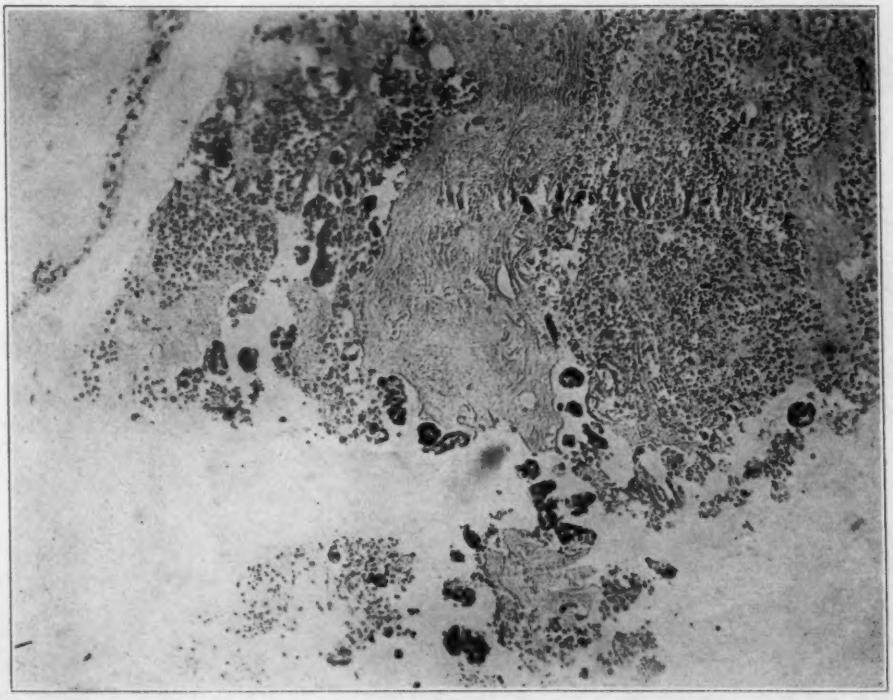

Fig. 1.—Pleural fluid from a case of adenocarcinoma of the ovary; low power magnification.

with a large eccentric nucleus or with several nuclei, sometimes showing mitotic figures, often vacuolated. Mesothelial cells which may or may not be clumped, occurring in transudates of long standing, are at times confusing. These must be carefully studied and differentiated by the criteria mentioned (fig. 2).

The cells often assume a glandular arrangement (eight cases) (fig. 3). The tumor cells may thus resemble the original tumor (fig. 4). In one case both pleural and peritoneal fluids were obtained, and both specimens showed the same type of cell.

A fluid may be positive at one examination and later appear negative. A patient with carcinoma of the pleura in whom the condition had metastasized from a bronchial carcinoma developed an effusion which on the first examination revealed many tumor cells. Two months later, a second tapping was done in which no tumor cells were found. It is possible that the fluid obtained from the second tapping came from an encysted effusion and not from the large pleural effusion. The

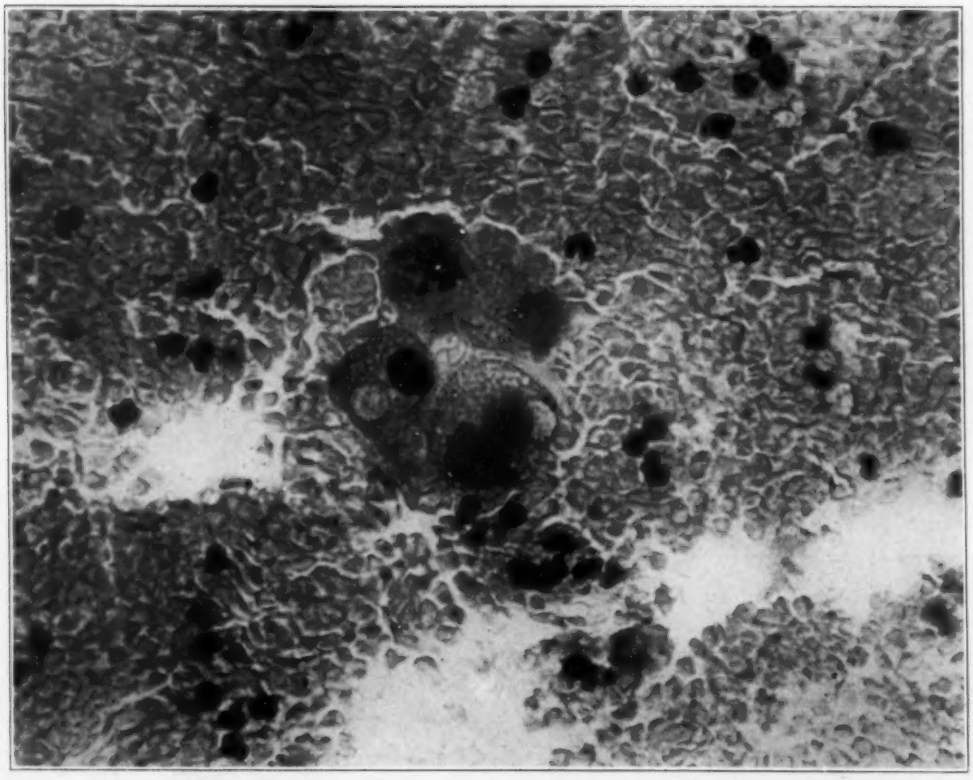

Fig. 2.—Pleural fluid from a case of metastatic carcinoma of the breast. Note the mitotic figure; high power magnification.

sputum in this case was treated by the same method and revealed no tumor cells.

Case 32 shows the necessity of careful search for tumor cells. While in the majority of cases cells are present in abundance, in this instance only one group of cells was found on which the diagnosis of malignant disease was made. A biopsy of a tumor of the neck revealed a metastatic carcinoma probably from the bronchus.

Tumor cells may appear in an effusion soon after the appearance of the fluid. In case 35 (autopsy confirmation), the patient developed

signs of pleural effusion while under observation. Tapping and study of the fluid a week after signs of fluid had developed showed numerous cancer cells. Figure 5 shows an adenocarcinoma in a pleural effusion which followed several months after removal of a breast for carcinoma in the male.

Four cases in which a positive diagnosis of tumor cells was made came to autopsy. All showed direct contact of cancer tissue with the

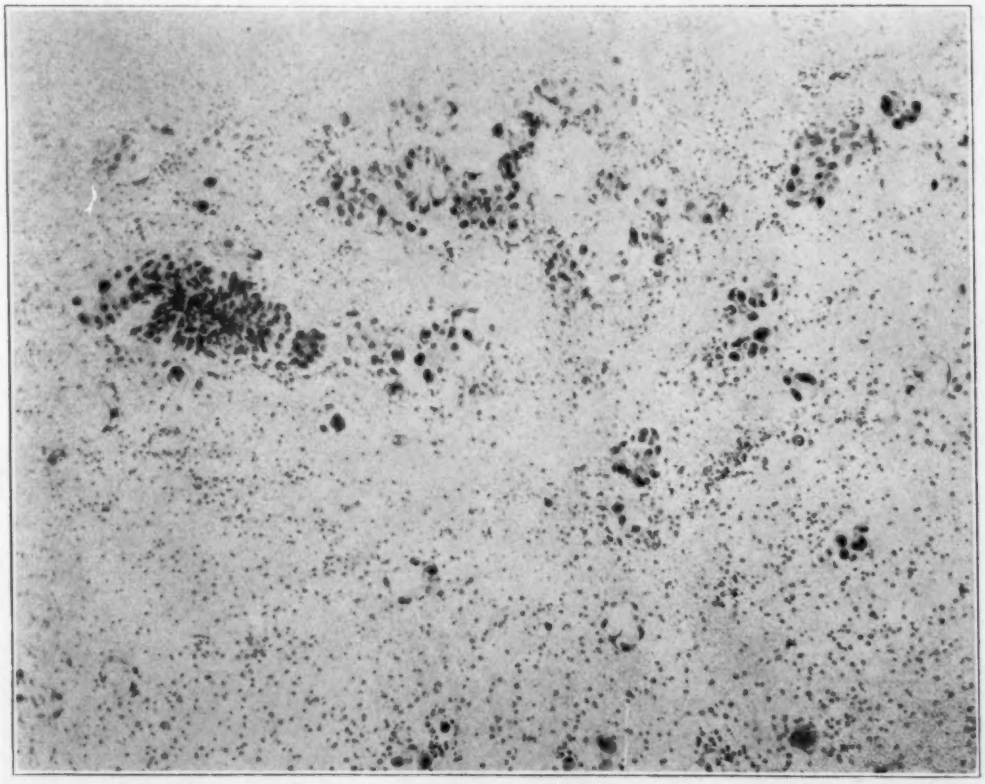

Fig. 3.—Pleural fluid from a case of adenocarcinoma of the bronchus. Note the alveolar arrangement; low power magnification.

effusions which had developed. Apparently this is essential before tumor cells are "shed" into the serous cavity.

The four negative examinations occurred in proved cases of carcinoma. Case 7 was one of carcinoma of the liver with metastatic glands in the retroperitoneal tissue. There was no actual contact of tumor and fluid. Case 28 was one of adenocarcinoma of the ovary with peritoneal involvement. Fluid in this case was obtained at operation and revealed a purely hemorrhagic fluid. Case 49 was one of carcinoma of the right bronchus and right lung combined with tuberculosis of

the base of the right lung. The fluid was small in amount and apparent only after pneumothorax.. Autopsy showed a disappearance of fluid in the base of the right lung with replacement by fibrinous adhesions. The effusion could possibly have been due to an active tuberculosis of the base of the right lung, though there was also a tumor of the pleura. The fourth case was one of abdominal effusion in association with carcinoma of the liver, in which no postmortem examination was made.

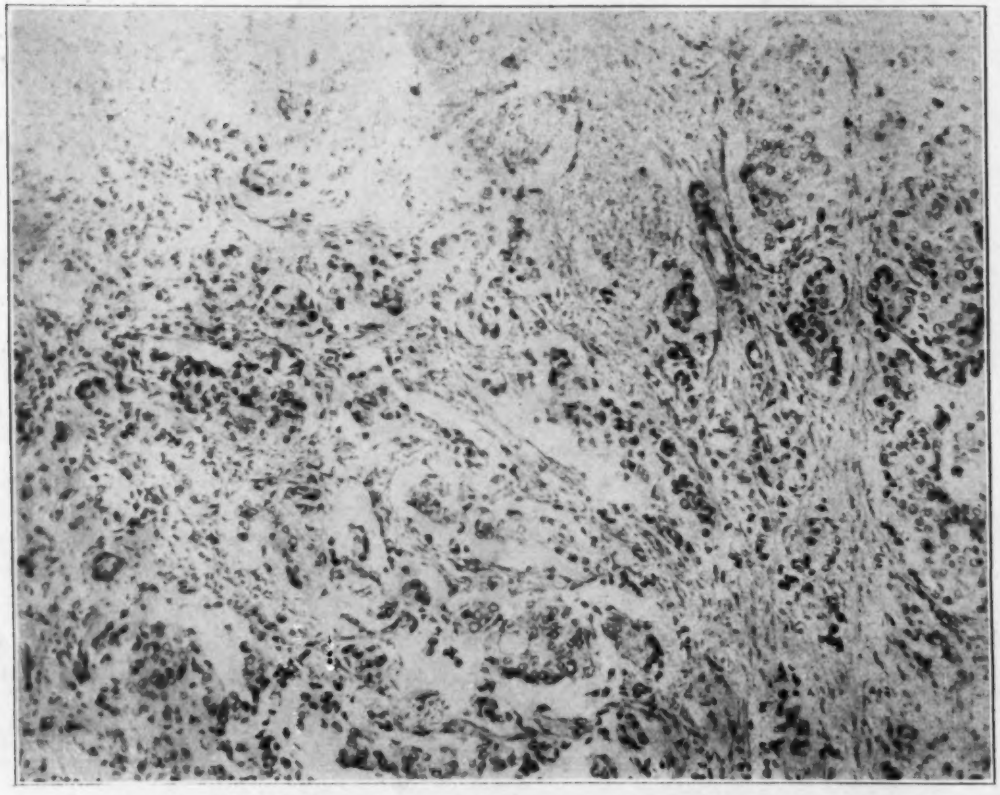

Fig. 4.—Section of gland of neck metastatic from adenocarcinoma of the bronchus in same case as in figure 3; low power magnification.

In none of the other examinations made could tumor cells be recognized as such, nor was a confirmed clinical diagnosis of cancer made in any of these cases. Whenever a carcinoma is in direct contact with the effusion that it has produced, one should expect to find malignant cells by the method described. There were no proved cases of sarcoma in the series studied. Zemansky has pointed out that a sarcoma is less likely to shed cells into its effusion than a carcinoma, owing to the more densely packed character of the sarcoma structure.

The appearance of the effusions varied from a clear straw-colored fluid as seen in transudates to turbid, bloody fluids. All specimens contained red blood cells in large amounts, more than in any other type of effusion. The specific gravity of the fluids ranged from 1.013 to 1.025; the average was 1.017. This figure is appreciably lower than that usually given in textbooks. There was no apparent relation between the specific gravity and the number of tumor cells present.

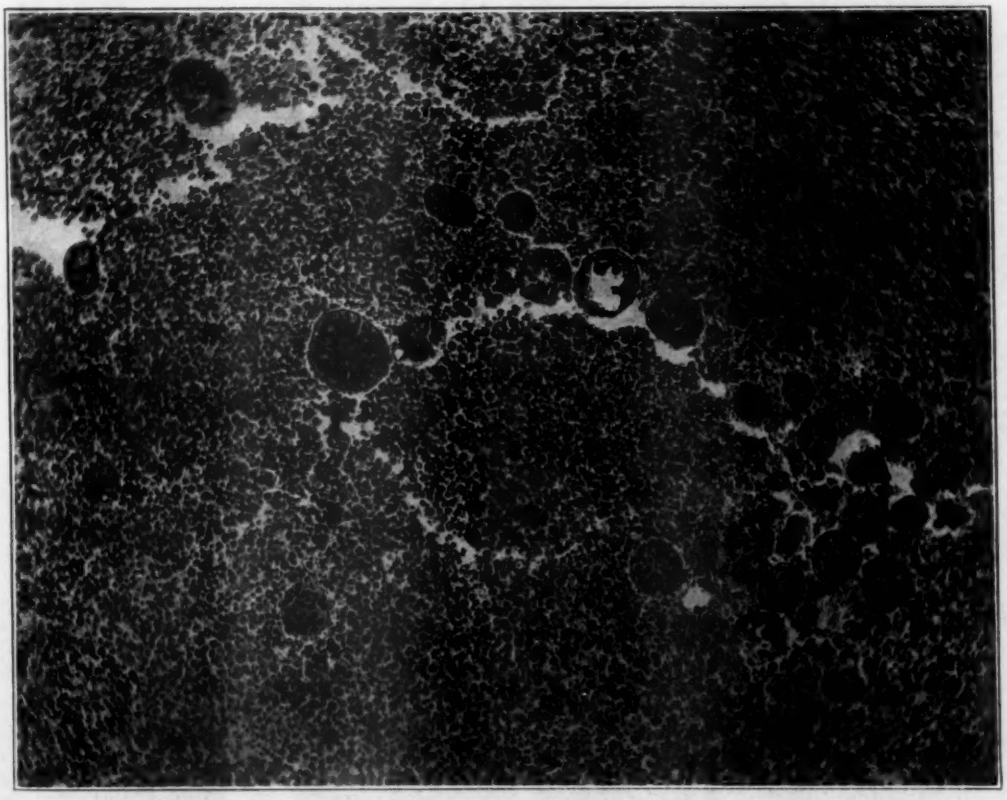

Fig. 5.—Pleural fluid from case of metastatic adenocarcinoma of the breast in the male. Note nests of tumor cells; low power magnification.

CARDIAC EFFUSIONS

There were ten cases of cardiac transudates, seven from the pleura and three from the peritoneum. All contained numerous red blood cells, less than in the cases of tumor and more than in the cases of tuberculosis. The predominating cell was the mesothelial cell, comprising more than 50 per cent of all the cells present. There were usually a few macrophages containing blood pigment, similar to the "heart failure" cell in the sputum in cardiac cases. The remaining

cells were chiefly lymphocytes and occasional polymorphonuclear neutrophils. The longer the effusion has been present, the greater the number of cells present. Clumped mesothelial cells may be mistaken for tumor cells. The former are usually smaller, more regular, have a single nucleus, show no mitosis, and do not stain so deeply as do the tumor cells. The specific gravity of these fluids varied from 1.008 to 1.014, with an average of 1.012.

TUBERCULOUS EFFUSIONS

There were twelve cases of tuberculosis in the series, ten from the pleura and two from the peritoneum. The predominating cell in nine specimens was the lymphocyte and in three the polymorphonuclear neutrophil. A few large mononuclears were usually present. In all cases red blood cells were present, but to a distinctly less extent than in tumor or cardiac effusions. The specific gravity ranged from 1.019 to 1.026; the average was 1.023. Eight of the sections were stained for tubercle bacilli, but none was found. This method, which theoretically should increase the possibilities of finding tubercle bacilli, is deserving of further study.

MISCELLANEOUS CASES

There were a number of miscellaneous cases with effusions which were studied. Two will be mentioned here. A pleural effusion in a case of Hodgkin's disease showed an equal mixture of lymphocytes and large mononuclear cells. There were about 10 per cent of cells containing elongated nuclei. A patient who had several large glands in the right side of the neck developed a right pleural effusion. Biopsy of a gland of the neck showed a chronic lymphadenitis, according to the pathologist. The effusion showed many large lymphocytic cells similar to the type of cell noted in the gland. This observation would suggest a lymphosarcoma. The patient is still under observation.

The urine from two patients with hypernephroma was studied, but no characteristic cells were found. Study of centrifugates prepared from urines is unsatisfactory.

CONCLUSIONS

1. Effusions resulting from carcinoma show "cancer cells" in a large majority of cases. These effusions show considerable blood. The specific gravity averages 1.017.

2. Cardiac transudates show a predominance of mesothelial cells. Red blood cells are abundant. The specific gravity averages 1.012.

3. Tuberculous effusions show a predominance of lymphocytes. Red blood cells are usually few. The specific gravity averages 1.023.

SURGICAL TREATMENT OF INTRATHORACIC TUMORS*

STUART W. HARRINGTON, M.D.
ROCHESTER, MINN.

The occurrence of intrathoracic new growths has been known for a great many years, but their recognition during life has been rare until comparatively recent years. The rapid advancement made in methods of thoracic diagnosis, especially since the use of the roentgen ray, has led to the early diagnosis of intrathoracic tumors and to the application of various types of treatment for the relief from symptoms. Roentgen rays and radium are probably the most commonly used agents in conservative treatment. In some of the cases of malignant tumors, such as the different types of malignant lymphomas and some of the sarcomas, there has been marked improvement. The lack of response of many of the tumors to the more conservative methods of treatment has stimulated surgical intervention with the view of radical removal of the diseased tissue.

I have previously reported five cases of intrathoracic tumors which were removed by transpleural operation. I am now reporting twelve additional cases, with a brief summary of the symptoms and methods of diagnosis and the surgical treatment. My purpose is to point out the difficulties encountered in many cases in establishing a definite clinical diagnosis of either benign or malignant tumors, to demonstrate the advisability of complete removal of benign tumors which may ultimately cause death from pressure on the surrounding organs, to show that the results of radical removal of malignant growths compare favorably with the results of surgical removal of malignant lesions elsewhere in the body and to emphasize the importance of early surgical intervention before the malignant growths have advanced beyond the possibility of surgical removal, and in the case of benign tumors, before they have caused serious injury to surrounding organs due to pressure or before they have undergone malignant change.

SIGNS AND SYMPTOMS

There are no characteristic signs by which early malignant intrathoracic tumors can be distinguished from benign intrathoracic tumors. The general condition of the patient is a great aid in establishing a diagnosis when this is correlated with the more special types of examination.

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* From the Division of Surgery, the Mayo Clinic.

The symptoms depend on the situation and the size of the tumor. They may be divided into two groups: those due to pressure or infiltration into the surrounding structures, and those due to inflammatory reaction in the tumor itself. The most common initial symptom is pain, which usually is in the wall of the chest at the site of the tumor, and which may be referred to different parts of the chest or arm, depending on the site of the tumor. In this group of cases, the initial symptom in fourteen cases was pain varying from two months to twenty-four years in duration. The pain was intermittent at the onset and often was precipitated by some inflammatory condition of the lungs, such as a severe cold or pneumonia, or often by extreme exertion. The pain in such cases is usually progressive, gradually becoming more or less constant. It is the usual symptom for which the patient seeks relief. The significance of this cannot be overestimated, as in several of the cases here reported the patients complained of pain in the chest for a long time before a thorough examination was made. In one instance, the patient had complained of pain in the upper right part of the thorax. that radiated down the arm, for more than twenty-four years. The first roentgenogram of the thorax was taken four years before admission, and the presence of a tumor was noted in the upper right part of the thorax. When this tumor was removed at operation it was found to have undergone malignant degeneration. It does not seem logical to assume that this tumor was malignant at the onset.

Dyspnea on exertion was noted in eleven cases; usually this is not noted on normal respiration, unless the tumor is enormous or if there is an associated pleural effusion. In three of the cases, there was a Horner syndrome, caused by pressure on the inferior cervical sympathetic ganglion. In all of these cases the tumor was malignant. Coughing and expectoration are not significant symptoms and are usually noted only when there is some irritation of the diaphragm or in dermoid tumors connected with or closely adherent to one of the main bronchi. Loss of weight is commonly noted in cases of malignant tumor and is often helpful in differentiating benign and malignant lesions, but at times it is noted also in benign lesions.

GENERAL EXAMINATION

Bulging of the wall of the chest was noted in five cases. In three of these cases there had been a history of previous injury; however, it is questionable whether the injury had any bearing as an etiologic factor. In twelve cases palpable tumor was not demonstrable. Pleural effusion may be present in either benign or malignant tumor but is more commonly associated with a malignant growth.

METHODS OF DIAGNOSIS

The physical examination is valuable in determining the general condition of the patient and is often of great aid in the differential diagnosis. It is of greatest aid, and often the deciding factor, in determining the advisability of surgical intervention.

The roentgen ray undoubtedly is the most valuable single method of diagnosis, and the importance of a thorough roentgenographic examination of patients who present suggestive symptoms cannot be overestimated. The single roentgenogram is useful in determining the presence of an intrathoracic tumor, and it affords definite knowledge as to its lateral and vertical position in the thorax. The lateral roentgenogram is of value in determining its position relative to the vertical and anteroposterior axes of the thorax and its relation to the anterior and posterior thoracic wall. The stereoscopic roentgenogram furnishes more definite knowledge as to the relation of the tumor to the normal structures within the thorax.

Artificial pneumothorax, when it can be employed in the absence of adhesions, is of great value in determining the relation of the tumor to the lung. In those cases in which the tumor is situated outside of the lung the introduction of oxygen gas in the pleural cavity will collapse the lung, and the tumor can be more distinctly visualized by roentgenographic methods. If the tumor is within the lung or if it is an anterior mediastinal tumor to which the median surface of the lung is adherent, the peripheral pulmonary tissue will collapse over the tumor. The posterior mediastinal tumors are usually not firmly attached to the parenchyma of the lung which will collapse away from the tumor readily on the introduction of oxygen. This method is of greatest benefit as an aid in distinguishing between intrapulmonary and extrapulmonary lesions.

Injection of iodized poppy seed oil 40 per cent within the bronchial tree often is of value in distinguishing between intrapulmonary and extrapulmonary lesions. Bronchoscopy has been a valuable addition to the diagnostic armamentarium. The presence of tumors outside of the lung, which cause pressure on the bronchi, often is suggested by signs of narrowing of the bronchi. This method is most useful in differential diagnosis, as in many instances of intrabronchial disease the diagnosis can be definitely established.

SURGICAL TREATMENT

The chief problems associated with the surgical removal of intrathoracic tumors are the difficulty of access through the bony incasement of the thorax and the danger of causing open pneumothorax with pulmonary collapse and mediastinal flutter.

The surgical approach depends, to some extent, on the site and type of tumor. If the tumor is attached to the lateral thoracic wall, I prefer to make the incision in that part of the wall of the chest which lies over the tumor; the site is determined by study of stereoscopic roentgenograms. If the tumor is in the anterior or posterior mediastinum, I prefer posterior thoracotomy, varying in vertical direction with the site of the tumor.

In several cases I have attempted extrapleural removal of posterior mediastinal tumors but always have found the pleura so adherent to the tumor that the pleural cavity was opened during its removal. This results in a condition of open pneumothorax, complicated by wide separation of the layers of the pleura, which delays healing; moreover, there is greater possibility of extensive pleural effusion. In one case the operation was performed in two stages. In the first stage an attempt was made to wall off the pleural cavity, but this failed because of pleural effusion which followed the first stage. In sixteen cases a transpleural operation was done in one stage. As no two cases are alike, the detail of the technical problem differs in each. This is given in the report of each case that is to follow.

The danger of open pneumothorax, with pulmonary collapse and mediastinal flutter, has been overcome by the use of intratracheal anesthesia induced by means of apparatus by which anesthetic gas and oxygen are administered under positive pressure. Ethylene or acetylene gas was used in all cases. The proper administration of the anesthetic should be in the hands of a skilled anesthetist. In cases in which partial collapse of the lung is required, the lung should be permitted to expand fully every four to five minutes during the operation. A suction pump should be applied to the intratracheal catheter before it is withdrawn to remove any mucus which may have accumulated in the trachea.

The after-care is important in these cases. All patients are given, intravenously, physiologic solution of sodium chloride or of dextrose. If there has been a fall of from 20 to 30 mm. of mercury in the blood pressure, a blood transfusion is given.

Postoperative pleural effusion occurs in practically all cases. In some cases aspiration will be required to relieve respiratory embarrassment, and if such embarrassment is not present, it will not be required, as the effusion will absorb rapidly. In many cases there is considerable hemorrhage, and in these cases, closed intercostal drainage should be instituted at the time of operation, and the tube should be removed at the end of from twenty-four to seventy-eight hours. Empyema is not uncommon after removal of infected dermoid cysts or in cases in which there has been injury to the pulmonary tissue. In these cases the patients are best treated by the closed method of intercostal drainage,

and in some cases resection of a rib may be required later. Patients with marked pulmonary collapse, dyspnea and cyanosis are best treated by being placed in an oxygen chamber; it often proves to be a life-saving procedure.

In nine cases in the group to be reported the tumor was benign and was completely removed by a transpleural one-stage operation. There were no deaths in this group. All of the patients have been completely relieved from symptoms, and a complete cure is to be expected. In this group of nine cases there was one case of osteochondroma, three cases of anterior mediastinal teratoma, three of posterior mediastinal neurofibroma, and two of cellular fibroma. In one of the cases of cellular fibroma, the growth originated in the upper posterior mediastinum, and in one, in the lower posterior mediastinum. In this group, it was not possible to make a definite clinical diagnosis of either a benign or a malignant lesion, and in several instances the clinical evidence was suggestive of a malignant condition. In one case bloody fluid had been aspirated from the chest on several occasions. I believe this group exemplifies the importance of exploration in all cases in which the diagnosis cannot definitely be established, and there is reason to believe, from the examination, that the tumor can be removed.

As would be expected, the results in cases of malignant tumors are not so satisfactory as in benign tumors. Of this series of seventeen cases, eight lesions proved to be malignant at the time of operation. In two of these cases the lesion was so extensive that only partial removal was possible. In six cases the tumor was removed completely. The results of operation in these eight cases are as follows:

Two patients are now living without evidence of recurrence, one patient three years and nine months after operation. The lesion in this case was an osteogenic fibrosarcoma originating on the wall of the chest; this was the only case in which a two-stage operation was performed. The other patient is living one year and seven months following operation. The growth in this case was a huge malignant endothelioma involving the entire lower part of the wall of the chest and diaphragm, necessitating resection of the portion of the diaphragm with the involved wall and closure of the opening with the relaxed diaphragm following the cutting of the phrenic nerve. I have heard from both of these patients recently, and they are doing their usual work.

The remaining six patients have died since operation, one patient of recurrence two years and two months after operation and after freedom from symptoms for a year and a half. The growth in this case was a fibrosarcoma and was known to have been present four years before operation; probably it was a benign fibroma at the onset. Four patients were benefited only slightly, if any, from the operation; in two of these

cases the growth was so extensive that exploration only was done, and in the remaining two cases the tumor was removed. These four patients died from recurrence within the first six months following the operation. The remaining patient, who had a teratoma which had undergone malignant degeneration to squamous cell epithelioma graded 4, died seven days following operation from cerebral hemorrhage; this was the only operative death in the series. The result in this group of malignant cases is not satisfactory, but it is at least encouraging in that a third of the patients were markedly benefited by the operation, and the results, I believe, compare favorably with those of highly malignant lesions elsewhere in the body. It exemplifies the importance of early diagnosis and early surgical intervention before the disease has progressed beyond the limit of radical excision.

Following is a summary of the history, results of general examination, methods of diagnosis, type of operation and the subsequent course in the twelve cases in which operation was performed and which have not been reported previously.

REPORT OF CASES

CASE 1.—A man, aged 56, was admitted to the Mayo Clinic on Jan. 23, 1928. The final diagnosis was intrathoracic osteochondroma, of the upper left anterior portion of the thorax. The chief complaint was pain in the upper left part of the chest of twenty months' duration. The patient had not had symptoms until twenty months before examination, when dull, aching pain in the upper anterior left portion of the chest had developed. The pain had been present more or less at night and frequently had kept him awake. For several days at a time he would have periods of freedom from the pain. It had radiated to the back, and down the left arm, and had become more constant, with various intervals of relief, but had remained of about the same degree of severity. About three months after the onset of pain, the patient noticed a tumor in the left upper part of the wall of the chest, just below the inner margin of the clavicle, which gradually had increased in size until it was about 5 cm. in diameter. Symptoms had not been severe enough to cause him to stop work. He did not cough or expectorate. There had been moderate dyspnea on exertion. Loss of weight had not been noted. Roentgenographic examination of the thorax, five years before admission, had disclosed evidence of a calcified area in the upper left part of the chest. There was no history of injury to the wall of the chest.

General examination gave negative results except for the presence of a fixed tumor just below the clavicle, on the left side, about 5 cm. in diameter. There was marked impairment on percussion, extending well beyond the limits of the palpable tumor. Moderate interference with transmission of breath sounds was noted. The hemoglobin was 76 per cent and the leukocytes, 8,000 per cubic millimeter. The Wassermann reaction of the blood was negative. Roentgenograms of the thorax revealed evidence of a dense, calcified area in the anterior part of the upper lobe of the left lung. Apparently it was chondroma of the cartilaginous ends of the the second and third ribs, extending into the cavity of the chest.

Anterior thoracotomy, with resection of half of the second and third ribs and intercostal muscle, was performed on Feb. 24, 1928. Transpleural removal of the

intrathoracic portion of the tumor was effected. The thoracic cavity was closed without drainage. Intratracheal ethylene anesthesia was used. The incision was made parallel with the clavicle; the pectoralis major was split and the pectoralis minor muscle was pushed aside. A soft, cystic tumor was found protruding from the second interspace and also in the midaxillary line from the third interspace. Apparently it arose from the juncture of the cartillage with the second rib, posteriorly. The pleura was firmly attached to the tumor and could not be separated from it. The entire tumor, with the pleura, intercostal muscles, and portions of the second and third ribs was removed. The lung was adherent to the tumor and had to be separated for a distance of about 5 cm. (fig. 1 *A*).

The operative diagnosis was large intrathoracic osteochondroma on the left side, 11 by 9 by 5 cm., arising from the cartilaginous juncture of the second rib posteriorly and extending into the cavity of the chest, causing partial collapse of

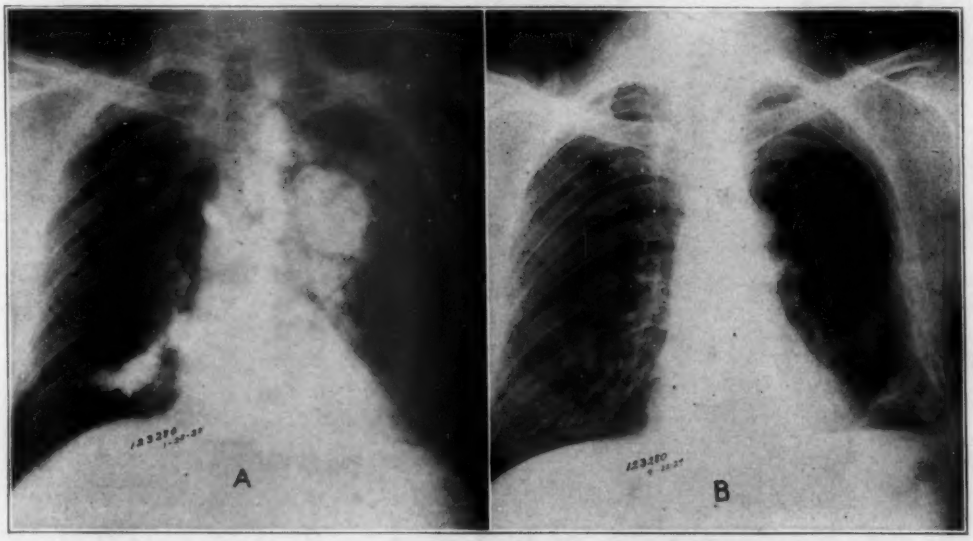

Fig. 1 (case 1).—*A*, roentgenogram taken at time of patient's admission showing dense calcified area in the anterior part of the left upper lobe, apparently chondroma of the cartilaginous ends of the second and third ribs extending into the cavity of the chest; *B*, roentgenogram taken fourteen months after transpleural removal of intrathoracic tumor with partial resection of the second and third ribs anteriorly and the ninth rib posteriorly. The area of decreased density in the upper portion of the left side of the thorax is due to removal of the wall of the chest. The left lung is fully reexpanded. There is no evidence of recurrence of tumor (osteochondroma).

the upper lobe of the left lung. The pathologic diagnosis was osteochondroma (fig. 1 *B*).

There was considerable shock following operation. On the second day, the pulse rate was 130 beats per minute and the temperature, 101 F. Moderate cyanosis was noted. This gradually became more marked and the patient was placed in the oxygen chamber on the sixth day. Following this he improved considerably and the cyanosis lessened. The left thoracic cavity was aspirated on the seventh day, and 750 cc. of bloody fluid was removed. This was repeated

on the eleventh and fourteenth days, and culture of the fluid showed a gram-positive coccus to be present. On the sixteenth day, the left thoracic cavity was drained by intercostal drainage after resection of about 2.5 cm. of the ninth rib in the posterior axillary line. The thoracic cavity was irrigated with a surgical solution of chlorinated soda (Dakin's solution), and the patient's condition improved progressively. The empyema cavity gradually became obliterated, and the patient was dismissed on the sixty-third day after operation, with the lung completely expanded and the wound entirely healed. The final result has been satisfactory. Six months after the removal of the tumor the patient returned for observation and was in excellent general condition (fig. 2).

Fig. 2 (case 1).—Scar of anterior thoracotomy fourteen months after transpleural removal of intrathoracic tumor. There is some retraction of the anterior wall of the chest which bulges on coughing. The patient's general condition is good; he has gained 40 pounds and has complete relief from symptoms.

It is of interest in this case that five years previously roentgenograms of the thorax disclosed a calcified area in the upper left part of the thorax and that symptoms were not noted until nearly three years later. There was no palpable tumor during this time, and the slight bulging was not noted until three months after the onset of pain. The pain was more or less constant after its onset. The reflex pain, radiating down the arm, is not uncommon in lesions of the upper part of the thorax. The good general condition of the patient, was clinical evidence that the

tumor was benign. Because of the apparent involvement of the second rib, the anterior surgical approach was used, which would permit removing the entire wall of the chest with the tumor. The necessity of removing such a large area of the wall of the chest with the tumor with only pectoral muscle, subcutaneous tissue and skin to close the thoracic cavity, resulted in collapse of the lung and an associated bloody pleural effusion which was aspirated on several occasions.

The oxygen chamber is of great benefit in cases in which there is marked pulmonary collapse. The patient should be given oxygen until there has been some reexpansion of the lung. However, I believe it is advisable to remove the patient from the oxygen chamber as soon as the condition will permit.

The empyema, in this case, probably resulted from a slight infection of the wound, as the fluid removed from the first aspirations was negative to culture. However, the empyema may have been the result of the repeated aspirations necessary for removal of the pleural effusion.

CASE 2.—A married woman, aged 31, was admitted to the clinic on July 16, 1928. The final diagnosis was left posterior mediastinal teratoma. The chief complaint was pain in the left arm and headache. There were multiple general complaints, such as migraine and constipation. She had had an indefinite pain in the left shoulder and arm more or less constantly for the year and a half previous to admission. She had had influenza six months before admission and since then the symptoms had been more marked. Considerable dyspnea on exertion had been noted. Her daily temperature had been from 99 to 100 F. Cough or expectoration had not been present. There had been some soreness of the left part of the chest, which had been more marked when she was lying down and which always had been present when she raised the left arm. Loss of weight had not been noted.

Results of general examination were essentially negative. The hemoglobin was 76 per cent and the leukocytes numbered 6,600 per cubic millimeter. The Wassermann reaction of the blood was negative. Roentgenographic examination of the thorax revealed in the posterior mediastinum, behind the heart, the shadow of a mass that apparently was attached to the spinal column, and was probably the shadow of a malignant tumor. Fluoroscopic examination showed a nonpulsile tumor (fig. 3).

On Oct. 10, 1928, left lower posterior thoracotomy was done, with removal of 12 cm. of the eighth rib and section of the seventh and ninth ribs at the costovertebral angle. Transpleural complete removal of the tumor was effected. Intratracheal ethylene anesthesia was used. The thoracic cavity was closed without drainage.

There was an irregular cystic tumor, arising, apparently, from the eighth intercostal space posteriorly and 5 cm. lateral to the thoracic aorta. It seemed to arise behind the pleura and had a broad elliptical attachment to the pleura. The tumor was adherent to the lower lobe of the right lung and also along the interlobar fissure between the lower and middle lobes. The adhesions were separated, and the tumor was found to arise from the posterior mediastinum, close to the thoracic aorta (fig. 4).

The operative diagnosis was of left posterior mediastinal teratoma, measuring 15 by 10 by 5 cm., attached to the thoracic wall, behind the pleura, at the eighth interspace posteriorly.

Pathologic examination revealed a cystic tumor lined with columnar epithelium, the wall of which contained cartilage and mucous glands. Probably it was part of the bronchial tree that had failed to develop. The tumor was filled with degenerated, cellular débris and mucus.

Convalescence was uneventful. The patient had little reaction from the operation. The pulse rate was 110 and the temperature was 100 F. on the second day. The temperature dropped to normal and the pulse rate to 70 on the sixth day and remained there throughout the remainder of convalescence. Dismissal from the hospital was on the twenty-second day, with the wound entirely healed. A roentgenogram of the thorax at this time was negative. The subsequent course has been satisfactory. In a letter received April 12, 1929, the patient stated that her general condition has improved greatly and she has gained 14 pounds (6.4 Kg.) in weight. She still has many general symptoms, none of which is referable to the tumor.

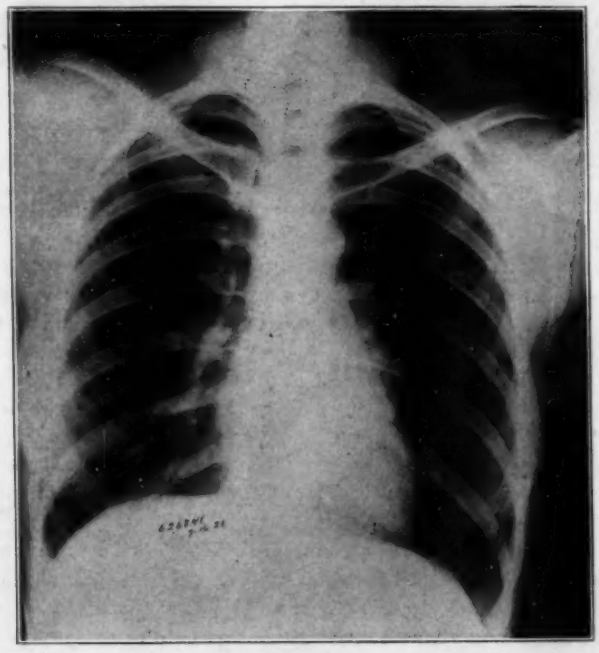

Fig. 3 (case 2).—Roentgenogram taken at time of patient's admission. The shadow extended from the posterior mediastinum posterior to the shadow of the heart in the left side of the chest at the level of the seventh and ninth ribs. The smooth outline suggests benign tumor.

It is questionable how much bearing the presence of the tumor had on the many general complaints of this patient, but it seems probable that the pain in the left shoulder and arm was the result of the tumor, espe-

cially since the symptoms were augmented by influenza. The roentgenograms of the thorax were difficult to interpret because of the position of the tumor behind the shadow of the heart. The somewhat infiltrating character of the margin of the tumor suggested that it might be malignant. However, the general condition of the patient did not indicate a malignant lesion. The tumor was readily exposed by posterior thoracotomy after the lung had been retracted forward. The lack of

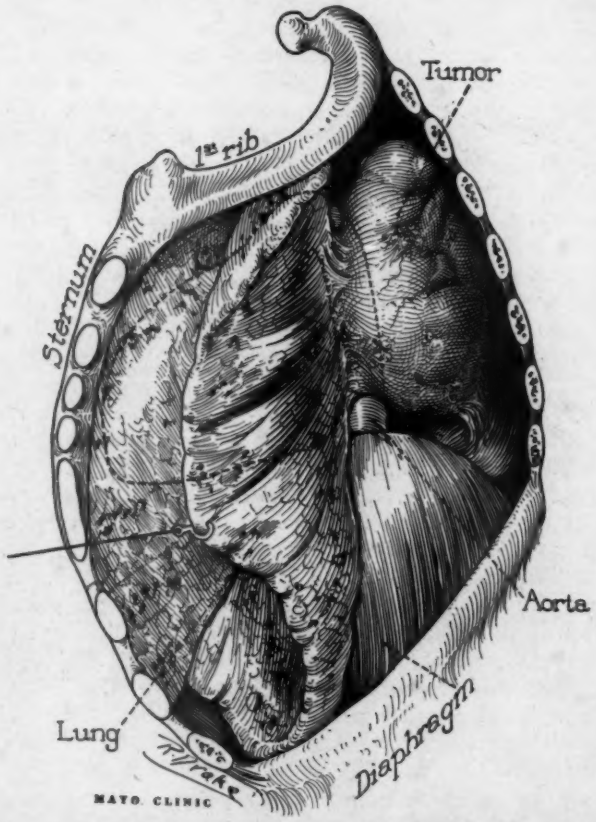

Fig. 4 (case 2).—The site of the left posterior mediastinal teratoma adherent to the hilum of the left lung, aorta and wall of the chest, posteriorly.

complications, postoperatively, is rather unusual considering the amount of adhesion between the lung and the wall of the chest which it was necessary to separate. Slight pleural effusion developed. However, it did not occasion any respiratory embarrassment; the fluid was not aspirated and was rapidly absorbed. The roentgenogram taken at the time of dismissal showed the lungs and pleura to be normal, with full expansion of the lung.

Case 3.—A married woman, aged 48, was admitted to the clinic on Feb. 8, 1929. The final diagnosis was intrathoracic teratoma (dermoid cyst) of the anterior and superior mediastinum projecting slightly more into the left than into the right side of the thoracic cavity. The chief complaint was of pain in the left anterior part of the chest and in the back, of fifteen months' duration. Her present symptoms had begun fifteen months before admission, at which time she had been ill for about a week, without fever, but with much pain in the left anterior part of the chest, above the heart. This had been diagnosed as pleurisy. The pain had been made worse by coughing, sneezing, breathing deeply and by pressure on the anterior, upper left portion of the wall of the chest. The patient had been unable to lie on the left side and in attempting to do so, she had become dyspneic and had been obliged to sit up. The first attack had lasted about a week and the pain gradually had subsided but never had disappeared entirely. She had had repeated attacks of this type, which had come on without any known cause, and in the more recent attacks, a choking sensation, associated with the pain, had developed. These attacks gradually had been getting more frequent and severe, until shortly before admission they had been almost constant. The pain had remained in the same situation, had radiated through the chest, into the back, and had been made worse by any exertion. Cough, abnormal sputum or hemorrhage were not present. The patient gradually had been losing weight and strength, and at the time of admission had been unable to do her work. The attacks had been so frequent and severe at night that she had been restless and unable to sleep.

The patient looked tired. She had lost 11 pounds (5 Kg.) in weight during the six months previous to admission. There was slight prominence of the second rib, just to the left of the sternum. Examination of the thorax revealed in the upper part of the mediastinum an area of dulness 11 cm. wide anteriorly and 14 cm. wide posteriorly. Urinalysis was essentially negative. The hemoglobin was 73 per cent and the leukocytes numbered 13,100. The Wassermann reaction of the blood was negative. Roentgenograms of the thorax revealed evidence of a tumor in the upper left part of the mediastinum, anteriorly, which probably was benign. The fluoroscopic examination showed that the tumor was nonpulsile and in the anterior mediastinum; the lateral view showed the posterior mediastinum to be clear, with a rounded tumor in the anterior mediastinum (fig. 5).

Left posterior thoracotomy was done on Feb. 16, 1929, with resection of the seventh and section of the eighth, sixth, fifth and fourth ribs and intercostal muscles. Transpleural complete removal of the anterior mediastinal tumor was effected. The thoracic cavity was completely closed without drainage (fig. 6).

Approach was through a posterolateral incision, made at the level of the seventh rib; the greater portion of the seventh rib was removed. After the ribs had been cut above and below, the pleural cavity was exposed by incision through the posterior periosteum of the seventh rib. The left lung was found to be adherent to the anterior wall of the chest. These adhesions were separated, and the upper lobe of the lung was found to be adherent to the cystic mass in the anterior and superior mediastinum. The median surface of the upper lobe of the lung was separated from the cystic mass and from the pericardium to which it was also adherent. The adhesions were firm and almost throughout necessitated dissection with the knife. After the lung had been separated from the tumor, the tumor was found to be adherent to the upper portion of the pericardium, to the pulmonary artery and to the ascending aorta, with an irregular projection extending under the arch of the aorta. The tumor also was adherent to the sternum and to the right mediastinal pleura, from which it was separated without opening into the right pleural cavity. The sac was ruptured during its removal, was found to be

multilocular and to contain sebaceous material and hair. The cut ends of the fourth, fifth, sixth and eighth ribs were then tied together and the pleural cavity was completely closed with running sutures of plain catgut. The lung was inflated by positive pressure just before the thoracic cavity was closed. The patient stood the operation satisfactorily. The blood pressure was 95 systolic and 75 diastolic, measured in millimeters of mercury, and the pulse rate was 120.

The operative diagnosis was of intrathoracic teratoma (dermoid) of the anterior and superior mediastinum, projecting slightly more into the left side of the thoracic cavity than into the right side. Pathologic examination disclosed a mediastinal dermoid cyst containing hair, sebaceous material, sweat glands, sebaceous glands and thymic tissue. The cyst probably had originated in the thymus gland (fig. 7).

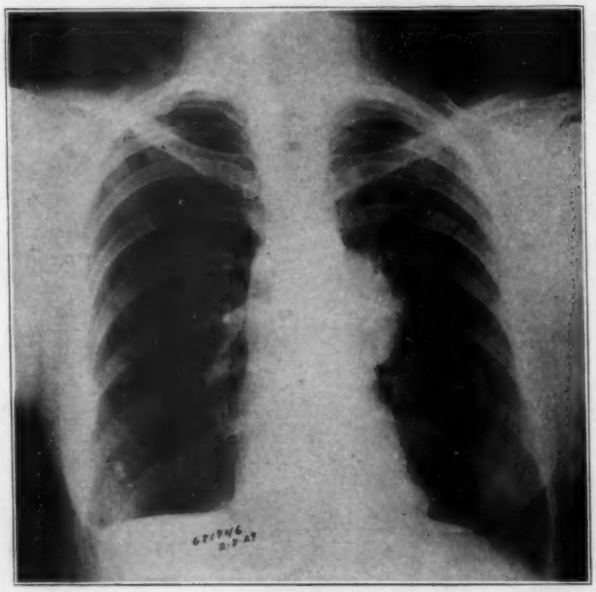

Fig. 5 (case 3).—Anteroposterior view taken at time of patient's admission showing tumor in the upper left mediastinum anteriorly, probably benign.

Convalescence was uneventful except for slight pleural effusion which did not require aspiration. The pulse rate remained at about 120 for three days and then gradually dropped to 90 by the tenth day. The temperature varied between 100 and 99.5 F. until the ninth day, when it dropped to normal and remained there throughout the ensuing period of convalescence. The patient was dismissed from the hospital and was permitted to return home on the twenty-fourth day, at which time the wound was entirely healed.

Roentgenographic examination of the thorax at the time of her dismissal showed the lung to be completely expanded. She returned for observation in about one month at which time she was found to be in excellent general condition. Symptoms were relieved completely (fig. 8).

The clinical history in this case is of interest in that the lesion was, at the onset, diagnosed as an inflammatory condition of the pleura. The

history was that of progressive, increasing pressure in the mediastinum. There was marked dyspnea, and a choking sensation, which probably were the result of pressure on the great vessels of the mediastinum. This pressure, in turn, was caused by gradual increase in the development of the tumor. The pressure became so great as to cause slight bulging at the sternal end of the second rib on the left side. The roentgenograms of the

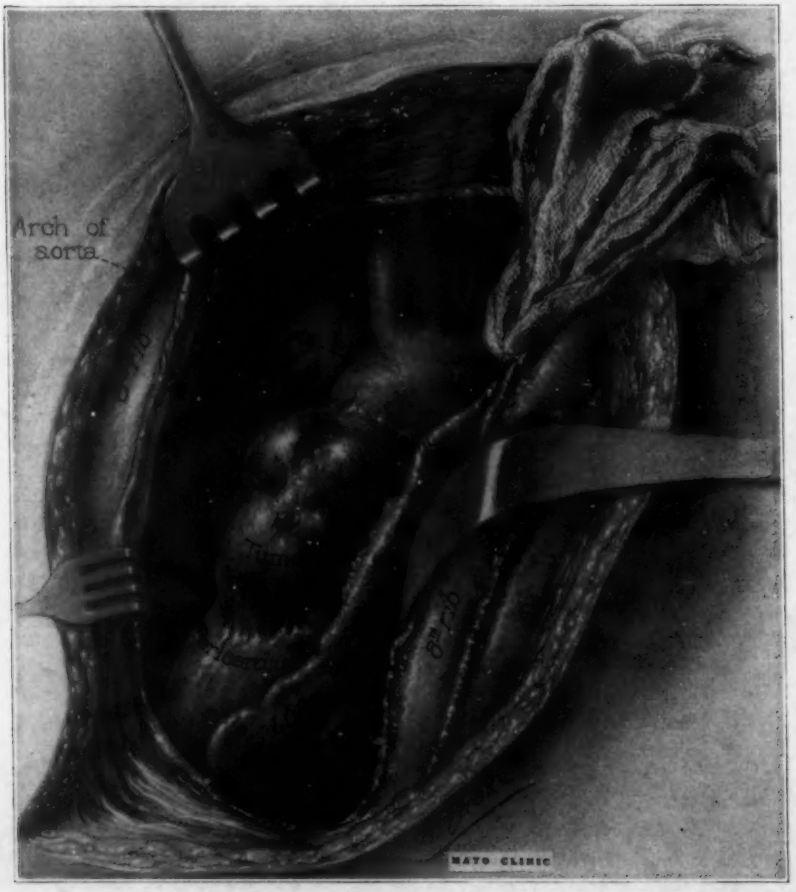

Fig. 6 (case 3).—Left posterior thoracotomy with resection of the seventh rib and transpleural exposure of the anterior mediastinal teratoma.

thorax were accurate in localizing the tumor and in giving the probable diagnosis in this case. The surgical approach, through posterior thoracotomy, was satisfactory in that the adherent lung was readily separated from the tumor. The lung was allowed partially to collapse. This brought the mediastinal structures clearly into view. The tumor then could be separated from the pericardium and great vessels with little

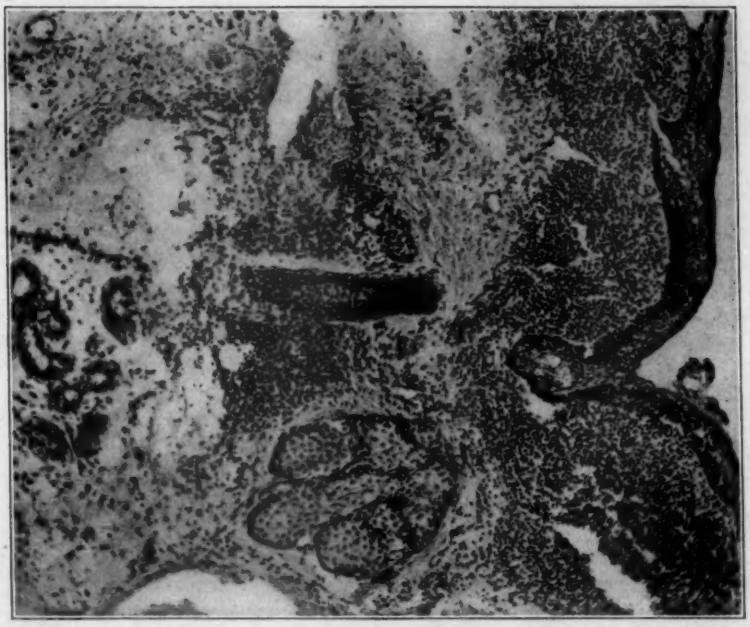

Fig. 7 (case 3).—Mediastinal teratoma (dermoid cyst) containing hair, sebaceous material, sweat glands, sebaceous glands and thymic tissue. The cyst measured 6 by 5 by 5 cm. and probably originated in the thymus gland.

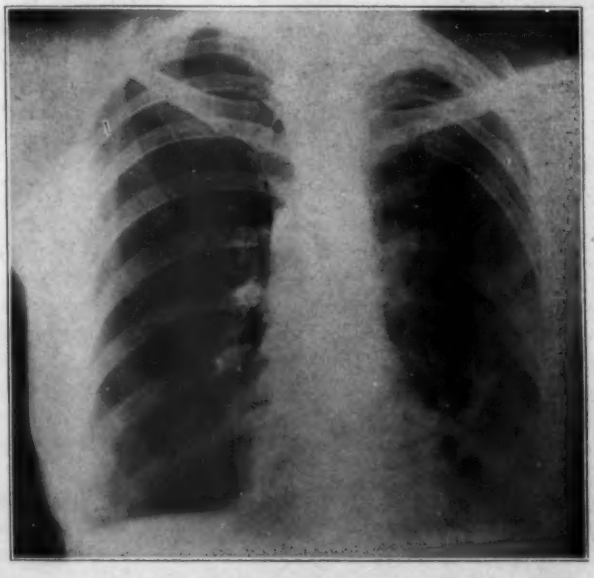

Fig. 8 (case 3).—Pleuritic adhesions of the left base and lung fully reexpanded six weeks after transpleural complete removal of the anterior mediastinal teratoma, resection of the seventh rib, and section of the eighth, fifth and fourth ribs.

danger of injury. The mediastinal pleura of the right pleural cavity could be separated easily from the wall of the tumor with the minimal danger of injury or of pneumothorax on the right side.

CASE 4.—A woman, aged 19, was admitted to the clinic on Oct. 18, 1928. The final diagnosis was intrapulmonary teratoma (congenital cyst) of the middle and lower lobes of the right lung. The chief complaint was pain in the right side of the chest of one year's duration. She had been in good health until one year before admission, when she had begun to have severe sharp pains in the right side of the chest, anteriorly and extending along the right costal margin posteriorly. The pain had been like that of pleurisy and had been noted especially on deep breathing, coughing, sneezing and so forth. The pain had been so troublesome that she had consulted her home physician one year before she had come to the clinic, but nothing had been found. The pain had been intermittent and had disappeared entirely for from two to three weeks at a time, until one month before admission, when she had become acutely ill and had been in bed for one week with severe pain in the anterior right portion of the chest. There had been marked dyspnea and moderate fever. A diagnosis of pneumonia had been made at that time. She had not had cough or night sweats and had not lost weight until shortly before she had come to the clinic. Dyspnea on slight exertion had been present for a year. Flecks of blood had been noted in the sputum for one month.

The results of general examination were essentially negative, except for the discovery of a localized area of dulness in the right anterior part of the chest, with absence of breath sounds in this area. There was evidence of slight loss of weight. There was moderate secondary anemia, with hemoglobin of 58 per cent. The Wassermann reaction of the blood was negative. Examination of sputum was negative for bacilli of tuberculosis. Roentgenograms of the thorax revealed a large, infiltrating tumor extending from the seventh to the tenth ribs posteriorly, which apparently arose in the hilum of the right lung. The lateral view revealed a large tumor in the right anterior portion of the thorax (fig. 9 *A* and *B*).

As part of the preoperative preparation, bronchoscopy was done Oct. 24, 1928. Results were indeterminate. There was no evidence of an intrapulmonary tumor but slight compression of the right main bronchus suggested the presence of an extrapulmonary tumor causing pressure on the bronchus.

Right posterior thoracotomy was done Oct. 31, 1928, with removal of the seventh rib. Transpleural complete removal of the intrathoracic tumor was effected. Transfusion of 500 cc. of blood was carried out. The pleural cavity was drained by intercostal closed drainage through the ninth intercostal space. Intratracheal ethylene and ether anesthesia were employed. Approach was through an incision made parallel with the seventh rib, from the posterior angle to the sternum. The seventh rib was removed by subperiosteal resection, and the pleural cavity was opened by incision through the posterior periosteum. On exploration of the right thoracic cavity, the diaphragm was found to be firmly adherent to the lower lobe of the right lung posteriorly. The adhesions were separated. The anterior portion of all three lobes of the lung was adherent to the lateral anterior wall of the chest and to the diaphragm. The adhesions were partially separated from the middle and upper lobes, allowing them to retract backward. It was possible to feel a large cystic tumor, completely surrounded by pulmonary tissue which was collapsed over the surface of the tumor. The tumor seemed to be in the center of the lung, with a small projection into the posterior mediastinum. As it was situated in the fissure between the upper and lower lobes, posteriorly, it was firmly adherent to all three lobes as well as to a

portion of the pericardial sac. The adhesions were separated, and a portion of the tumor was found close to the hilum, completely surrounded by pulmonary tissue of the upper lobe. This pulmonary tissue had to be cut through in order to uncover the upper portion of the wall of the cyst. The cyst was inflammatory and was so adherent to the surrounding pulmonary tissue that it had to be dissected free with a knife. It ruptured during removal and was found to contain about 250 cc. of dark, brownish-green fluid. After the capsule had been dissected away from the surrounding tissues of the middle and upper lobes, the pulmonary tissue was resutured with catgut. The opening in the pleura was completely closed with plain catgut and the muscles of the thoracic wall were resutured. The incision in the skin was then completely closed (fig. 10).

The operative diagnosis was of a large intrathoracic cystic teratoma, 10 by 15 cm., originating close to the hilum of the right lung, extending partly into the

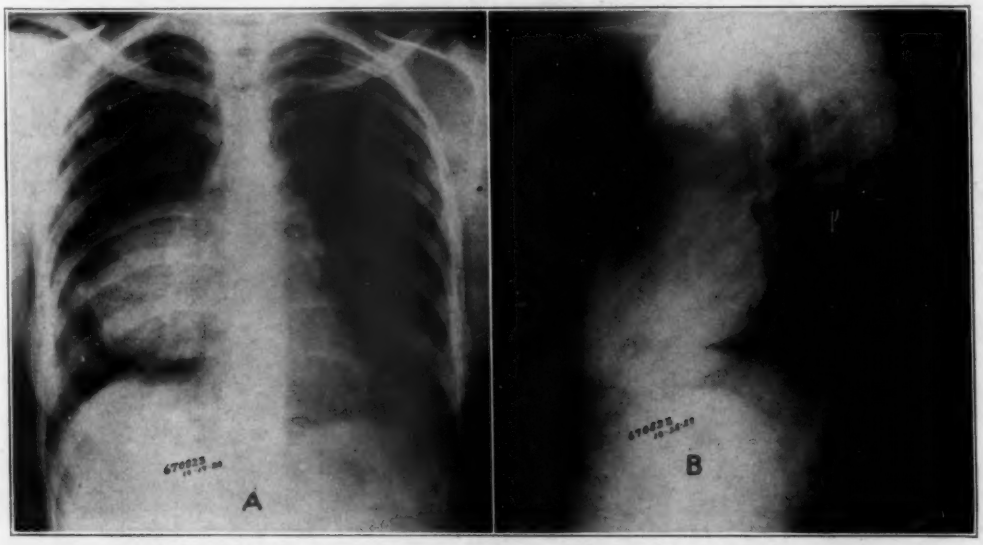

Fig. 9 (case 4).—*A*, anteroposterior view at time of patient's admission showing large infiltrating tumor extending from the seventh to the tenth ribs posteriorly, apparently arising in the hilum of the right lung; *B*, lateral view at time of admission showing large tumor of anterior portion of the right side of the thorax.

fissure between the upper and lower lobes of the lung posteriorly, and completely surrounded by pulmonary tissue, to which it was adherent.

Pathologic study disclosed a cystic mass composed of a cyst with a fibrous wall which was filled with clotted blood. There was no definite epithelial lining. A solid area at one end of the tumor was composed of salivary glands, and of ducts and fibrous tubes, both lined with columnar epithelium that closely resembled epithelium of the bronchi.

The immediate reaction to the operation was satisfactory. The pulse was 140 and the temperature 103 F. on the first day. The temperature dropped to normal on the fourth day and the pulse rate gradually dropped to 86. The intercostal drainage tube was used as a channel for irrigation with a surgical solution of

chlorinated soda, and in this way bloody fluid was removed from the pleural cavity. After the eighth day, fluid could not be recovered, and the tube was removed on the tenth day. Two days later the temperature gradually began to rise. On the seventeenth day the pleural cavity again was aspirated and fluid was found. Following the removal of the fluid the temperature dropped to normal and remained normal until the twenty-eighth day; then it suddenly rose to 101 F. A slight cold developed; the patient ran a septic temperature, which rose to 102 F. On the twenty-ninth day, therefore, a portion of the ninth rib was resected, and

Fig. 10 (case 4).—Transpleural exposure of large right posterior mediastinal teratoma adherent to the diaphragm and to the middle and lower lobes of the right lung which were partially collapsed and adherent over its surface.

a tube was inserted in the chest. A small empyema cavity was found. The temperature dropped to normal on the eighth day following the insertion of the tube. The tube gradually was removed, and the empyema cavity was entirely obliterated in three weeks following this operation. The patient was dismissed two months after the removal of the intrathoracic tumor. The lung was completely expanded and the patient was relieved from symptoms (fig. 11).

The clinical history in this case closely simulated that of the preceding case in that at the onset the condition was thought to be an inflammatory pleural or pulmonary lesion. The presence of moderate fever during the attacks of illness would indicate an inflammatory reaction in the tumor itself, which probably caused gradual increase in the size of the tumor which, in turn, produced progressive symptoms of pressure within the mediastinum and thorax. In this instance, the tumor was of sufficient size to cause partial collapse of the lung. The bronchoscopic examination was of aid in ruling out intrapulmonary lesions, and the slight compression of the right main bronchus suggested an extrinsic

Fig. 11 (case 4).—Slight elevation of diaphragm. Normal appearance of lungs two months after transpleural complete removal of mediastinal teratoma and resection of seventh rib and portion of ninth rib.

tumor. The value of latent roentgenograms was exemplified in this case. The anteroposterior stereoscopic views showed evidence of an infiltrating type of tumor, suggesting that a malignant condition was present. This hazy outline probably was the result of the lung being collapsed around the surface of the tumor. The lateral views disclosed that the posterior surface of the tumor had a smooth round appearance which strongly suggested the presence of a benign lesion. The surgical approach by posterior thoracotomy was satisfactory and the marked inflammatory reaction in the tumor was evidenced by the firm adhesions

to the lower lobe of the lung which made it necessary to cut through the pulmonary tissue in order to remove the capsule of the tumor. Because of the marked inflammatory reaction of all of the surrounding structures and the numerous bleeding points in the bed of the tumor, it was thought best to institute intercostal closed drainage in this case at the time of the operation. This complication prolonged convalescence from three to four weeks before the empyema wound was entirely healed.

CASE 5.—A man, aged 49, was admitted to the clinic on Feb. 12, 1929. The final diagnosis was large anterior and superior mediastinal multilocular cystic squamous cell epithelioma, graded 4, probably malignant degeneration of a teratoma. The chief complaint was pain in the left part of the chest and the left arm, of four years' duration. The patient first had noticed pain in the left upper anterior part of the chest and the left arm four years before admission. This had come on by spells and had been more or less severe. The patient had been fairly well until about three months before he came to the clinic, when the pain had become more or less constant and severe and sedatives had been required. For nine months he had noticed that it was hard for him to lie down, particularly on the left side, because of the pain and drawing sensation in the anterior upper portion of the chest. He had felt much better when he was up and about and he had not coughed or expectorated. He had had occasional night sweats and sharp pain in the left shoulder. The appetite had been fair, but he had gradually lost strength. He had lost 24 pounds (10.9 Kg.) during the last seven months.

General examination revealed moderate emaciation and moderate arteriosclerosis. There was dulness to percussion, and bronchial breathing in the upper left part of the chest both anteriorly and posteriorly. Moderate clubbing of fingers also was noted. Urinalysis gave negative results. The hemoglobin was 78 per cent and the leukocytes numbered 6,800 per cubic millimeter. The Wassermann reaction of the blood was negative. Roentgenograms of the thorax revealed evidence of a rounded, somewhat lobulated tumor in the left part of the mediastinum. The lateral view showed the tumor to be in the middle portion of the mediastinum. Fluoroscopic examination showed that the tumor was pulsile, possibly an aneurysm (figs. 12 *A* and *B*).

Preoperative preparation included left pneumothorax that was done for diagnosis. Roentgenograms taken after pneumothorax revealed evidence that there was a large lobulated tumor in the right lung, situated about midway anteroposteriorly, and that the lung was collapsed over the tumor. Fluoroscopic examination showed the tumor to be nonexpansile.

Posterior left thoracotomy was done on Feb. 20, 1929, with resection of 16 cm. of the eighth rib and section of the ninth, seventh, sixth and fifth ribs. Transpleural complete removal of the intrathoracic tumor was effected. Transfusion of 500 cc. of blood was carried out. The thoracic cavity was closed without drainage. Intratracheal ethylene anesthesia was used. The left pleural cavity was opened by incising the pleura through the periosteum of the eighth rib. On exposing the anterior mediastinum, a multilocular, lobular, hard cystic mass could be felt between the lung and the pericardium and great vessels. The greater portion of the tumor extended into the left side of the thorax. The entire median portion of the lung between the upper and lower lobes was firmly adherent over the surface of the tumor, and the upper lobe was about a third collapsed by the tumor. The lung also was firmly adherent to the parietal pleura at the apex. The adhesions were old and vascular and had to be cut and ligated.

After the lung was dissected from the parietal pleura at the apex, the median portion was dissected from the tumor. The adhesions were so firm that sharp dissection with a knife was necessary. In some areas, it was necessary to remove the visceral pleura because of the firm adhesions. After the lung had been dissected free, the mass was found to be adherent to the upper third of the pericardium and to the great vessels in the mediastinum. Dissection was then started from the pericardium. The wall of the cyst was ruptured in an attempt to remove it and about 700 cc. of dark brownish fluid and granular material escaped. The sac was multilocular and lobulated and was firmly adherent to the pericardium, pulmonary artery, ascending aorta and the arch of the aorta, as well as to the right mediastinal pleura. It was impossible to follow any line of

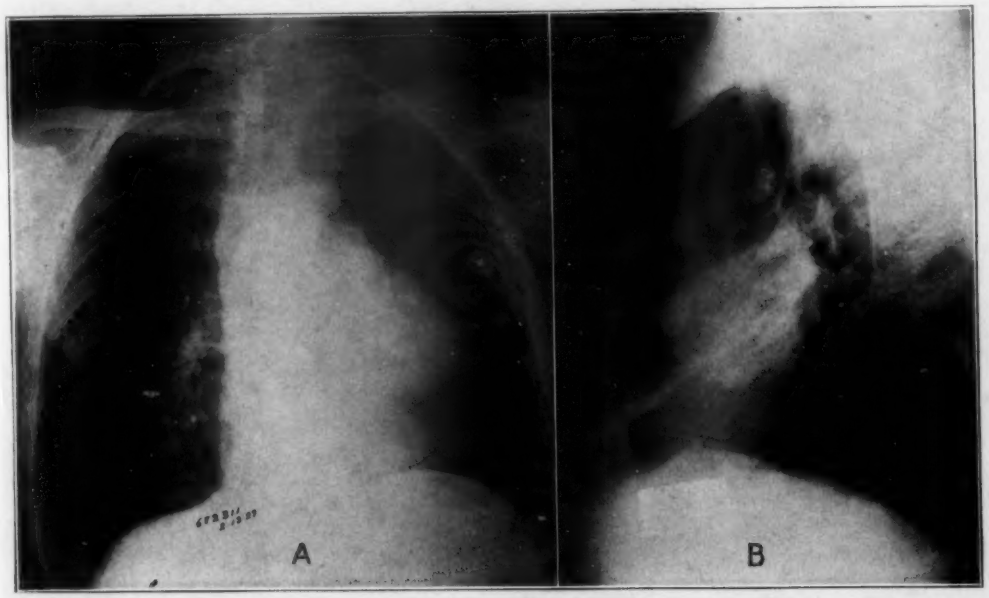

Fig. 12 (case 5).—*A*, anteroposterior view on patient's admission, following artificial pneumothorax showing large rounded tumor of the left lung, pneumothorax, and collapse of the lung around the tumor; *B*, lateral view following artificial pneumothorax showing large lobulated tumor about midway anteroposteriorly, apparently arising from the anterior mediastinum. The posterior mediastinum is clear.

cleavage and the entire capsule had to be dissected away from these structures. A small portion of the outer wall of the sac was left adherent to the pulmonary artery and another small portion, which had projected under the arch of the aorta, was left in place. After the tumor had been removed, all bleeding points were controlled by ligatures. The cut ribs were sutured together with chromic catgut and the thoracic cavity was closed without drainage. The patient's condition at the close of the operation was fair. The blood pressure was 95 systolic and 75 diastolic, and the pulse rate was 116 (fig. 13).

The operative diagnosis was large anterior and superior mediastinal multilocular cystic squamous cell epithelioma, graded 4, probably malignant degeneration of a teratoma. The tumor was 20 by 18 by 15 cm. and was situated in the anterior and superior mediastinum, extending slightly into the right pleural cavity, and was adherent to the right pleura. There was a large projection into the left pleural cavity, with partial collapse of the left lung. Pathologic examination disclosed a degenerated, infected, squamous-cell epithelioma, graded 4 (fig. 14).

The patient's immediate reaction was satisfactory. The pulse rate varied from 110 to 130 for the first five days. The temperature was 101.5 F. on the second day and dropped to normal on the third day, with remissions to 100; it varied between 100 and normal until the sixth day. The respiratory rate ranged between 24 and

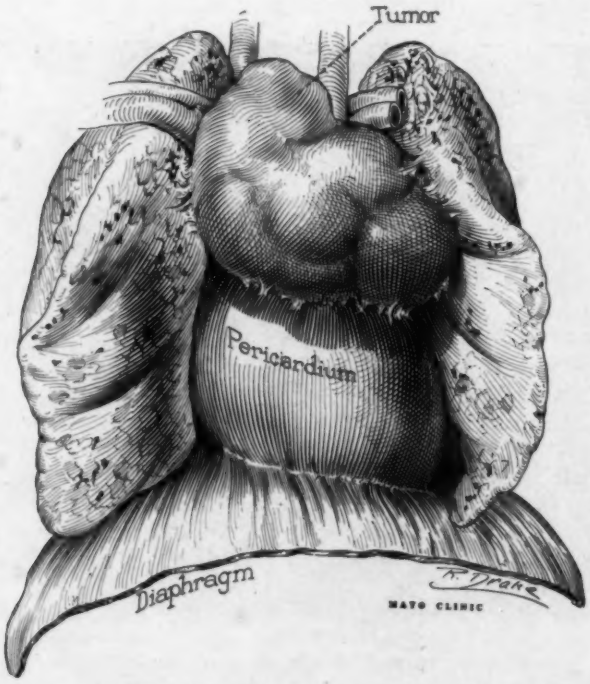

Fig. 13 (case 5).—Site of the large multilocular cystic anterior mediastinal tumor firmly adherent to the pericardium, arch of the aorta, pulmonary artery and median surface of the left lung.

32 until the seventh day. Bloody fluid was aspirated daily from the chest after the third day. The patient's condition seemed to be progressing satisfactorily until the evening of the sixth day, when he had a sudden rise of temperature to 105 F. with increase in pulse rate from 110 to 150 and in respiratory rate to 44. He became irrational, partial paralysis of the left side developed and he died on the morning of the seventh day from cerebral embolism.

The duration of symptoms, in this case, over a period of four years, would suggest the presence of a benign tumor which had undergone malignant degeneration. It is the largest tumor which I have encoun-

tered situated in the anterior mediastinum. Its situation was like that of the tumors in the two preceding cases; however, this tumor was much larger and even more adherent to the surrounding structures. The capsule of the cyst was under marked tension from the contained fluid, and it was ruptured during its removal. The greater portion of the wall had to be dissected in pieces away from the surrounding structures and was found, on microscopic examination, to consist almost entirely of fibrous tissue except a portion of it which was situated in the anterior mediastinum above the arch of the aorta. It was in this portion of the capsule of the tumor that squamous cell epithelioma was found. The

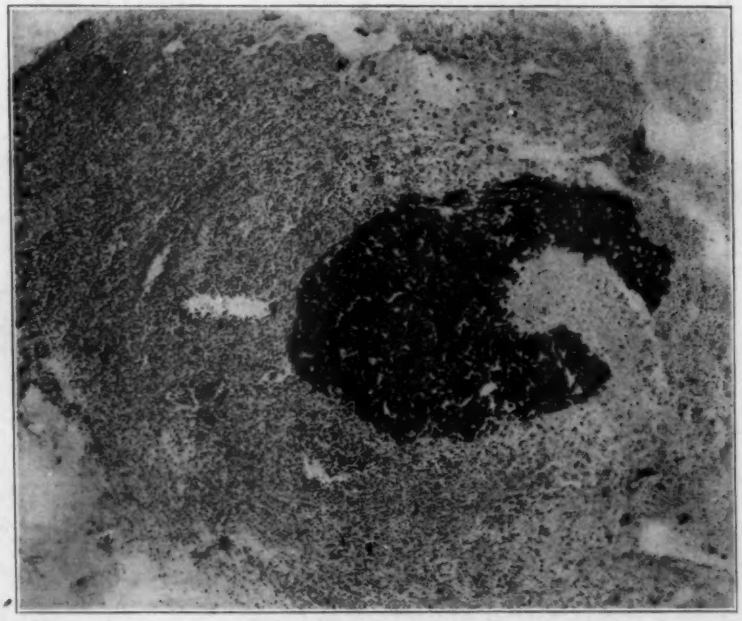

Fig. 14 (case 5).—Squamous cell epithelioma, graded 4 (probably a malignant degeneration of a teratoma).

definitely encapsulated nature of the tumor and the fact that it had not infiltrated into the surrounding structures, indicate that originally it was probably a benign tumor. This emphasizes the importance of early diagnosis and of early surgical intervention in all cases of intrathoracic tumor except those in which a hopeless prognosis is obvious. This case was the only one in the whole series in which there was an operative death. The weakened condition of the patient and his loss of weight during the last three months were unquestionably factors in his inability to survive the operation. The partial collapse of the lung had produced slight bronchiectasis in the lower lobe, and this may have been a factor in the production of the cerebral embolism. Examination at necropsy

showed that the tumor had been removed completely and that the operative field was in good condition. There was no remaining evidence of malignancy in the surrounding structures.

CASE 6.—A married woman, aged 35, was admitted to the clinic on Feb. 14, 1928. The final diagnosis was intrathoracic neurofibroma of the right part of the wall of the chest. The chief complaint was fatigue of two years' duration. There was soreness in the right shoulder and tumor of the right wall of the chest of eight years' duration.

The patient came to the clinic with multiple complaints of the type heard in cases of chronic nervous exhaustion, with marked anemia of indeterminate type. The hemoglobin was 36 per cent. This probably was responsible for a great many of the patient's general symptoms. She had a small tumor of the right lower portion of the thoracic wall, between the eighth and ninth ribs, in the midaxillary line. She complained of periodic pain at the site of this tumor. The growth was slightly movable, and seemed to come through the wall of the chest. She had noticed the presence of the tumor about eight years before admission, and there had been gradual increase in size. She was placed in the hospital under study for the anemia and was given two transfusions of blood, with only slight improvement in the condition. Removal of the intrathoracic tumor was advised.

General examination revealed a tumor at the eighth intercostal space, in the midaxillary line, on the right side. The tumor was freely movable. The hemoglobin was 36 per cent; erythrocytes numbered 3,650,000 and leukocytes 8,000 per cubic millimeter. Roentgenograms of the thorax showed evidence of a circumscribed tumor arising from the parietal pleura, in the lateral aspect of the lower right part of the chest, and it probably was benign (fig. 15 *A*).

Preoperative preparation included transfusion of 500 cc. of blood, March 2, 1928. This was given because of the marked anemia of indeterminate, although probably secondary, type.

Posterior right thoracotomy, with partial removal of the seventh, eighth, ninth and tenth ribs, was done March 7. Transpleural complete removal of the intrathoracic neurofibroma was effected. The thoracic cavity was closed without drainage. Intratracheal ether and ethylene anesthesia was used. Incision was made over the eighth rib, on the right posterolateral portion of the wall of the chest, and a small protruding part of the tumor was found between the eighth and ninth ribs. The large mass of the tumor was protruding into the thoracic cavity and extended from the seventh to the tenth ribs. The ribs were resected well beyond the limits of the tumor and were removed, in one mass, with that portion of the wall of the chest and pleura which was adherent to the tumor. The latissimus dorsi and serratus muscles were stitched over the area of the wall of the chest and the wound was closed without drainage.

The operative diagnosis was intrathoracic degenerating neurofibroma of the right side of the chest, situated in the posterior axillary line and protruding between the eighth and ninth ribs. Pathologic examination revealed a cystic, hemorrhagic, degenerating neurofibroma. Convalescence was uneventful except for pleural effusion on the right side which necessitated aspiration on two occasions. The patient was dismissed from the hospital and from my care on the twenty-fourth day, with the wound entirely healed. At the time of her last visit, one year following the operation, she had no respiratory symptoms and had gained about 23 pounds (10.4 Kg.). The roentgenograms of the thorax showed the lungs to be normal. The hemoglobin had increased to 59 per cent and the erythro-

cytes to 4,380,000 per cubic millimeter. The leukocytes numbered 7,600 per cubic millimeter (fig. 15 *B*).

The secondary anemia which was present in this case was not the result of the tumor but was an associated condition. Operation was advised because of the presence of the tumor in the thorax which was undoubtedly the cause of the pain in the right lower part of the thorax. This tumor was under so much tension under the pleura that it had bulged through the eighth intercostal space. Since the opening in the pleural cavity was closed with muscle of the wall of the chest, accumulation of serum resulted which necessitated aspiration. Marked improvement in the patient's general condition followed the operation. Not only

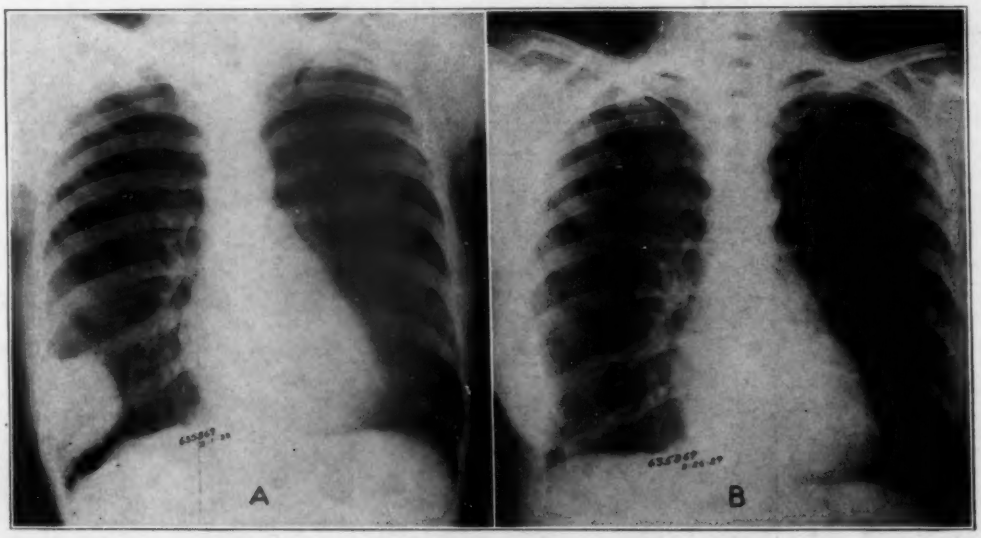

Fig. 15 (case 6).—*A*, circumscribed tumor in the lower portion of the right side of the chest presenting between the eighth and ninth ribs in the posterior axillary line and extending into the thorax from the seventh to the tenth ribs at time of patient's admission; *B*, roentgenogram taken one year after transpleural removal of large intrathoracic neurofibroma and partial resection of seventh, eighth, ninth and tenth ribs. The lung is fully reexpanded.

did she have entire relief from pain in the right lower portion of the thorax, but the anemia also showed marked improvement, which probably resulted from the improved general condition.

Case 7.—A married woman, aged 46, was admitted to the clinic on Sept. 15, 1926. The final diagnosis was of large intrathoracic neurofibroma in the right upper part of the posterior mediastinum. The chief complain was palpitation, and dyspnea on exertion, of two years' duration.

Two years before admission the patient had noted loss of initiative and of energy and was easily fatigued. Palpitation of the heart, shortness of breath on

exertion and tremor with marked nervousness gradually had developed. The symptoms had become more severe during the six months previous to admission. For one month she had noticed edema of the feet. She had lost 15 pounds (6.8 Kg.). She had gone to a hospital six weeks previous to her visit to the clinic and had been given treatment with iodine for three weeks, during which time she had regained 5 pounds (2.3 Kg.). She had had some difficulty in swallowing toast or crackers, which seemed to stick in her throat.

Results of general examination were essentially negative except for signs of the presence of a solid tumor in the upper posterior right portion of the thorax. The hemoglobin was 72 per cent, erythrocytes numbered 4,350,000 and leukocytes 5,800 per cubic millimeter. The Wassermann reaction of the blood was negative. The basal metabolic rate was —8. Roentgenograms of the thorax gave evidence of a large, circumscribed tumor in the upper part of the right lung. Fluoroscopic

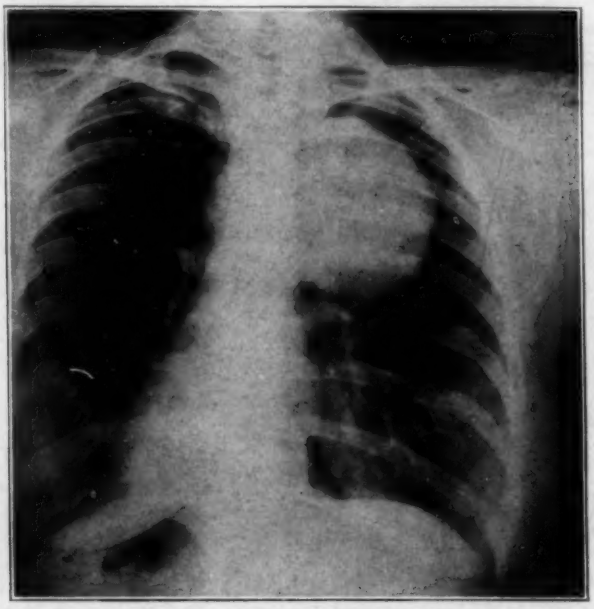

Fig. 16 (case 7).—Large circumscribed tumor in the upper portion of the right side of the thorax extending from the third to the eighth rib posteriorly at time of patient's admission.

examination indicated that there was a nonpulsating tumor in the upper right part of the chest and that probably it was benign (fig. 16).

High right posterior thoracotomy was done Sept. 25, 1926, with removal of a portion of the seventh rib and section of the fourth, fifth, sixth and eighth ribs. Extrapleural complete removal of intrathoracic tumor was effected. The thoracic cavity was closed without drainage. Intratracheal ether anesthesia was used. A posterolateral incision was made between the scapula and the spinal column, along the seventh rib, and about 12 to 14 cm. of the rib was removed subperiosteally. The posterior periosteum then was incised and the pleura was separated from the thoracic wall. The sixth, fifth, fourth and eighth ribs then were divided, and the pleura was separated from the wall of the thorax, from the posterior to anterior

aspect, without opening into the thoracic cavity at any point. The tumor was adherent to the thoracic wall, close to the spinal column, at the level of the fifth rib. The pleura was adherent to the tumor; the anterior portion could not be entirely separated from the tumor and was removed with it. The opening in the pleura was sutured with plain catgut. The ribs were drilled and sutured together with chromic catgut and the wound was completely closed (fig. 17).

The operative diagnosis was of large, intrathoracic neurofibroma of the upper right portion of the posterior mediastinum. Pathologic examination disclosed a neurofibroma, weighing 234 Gm.

Moderate shock immediately followed operation. On the third day, the temperature was 102 F., the pulse was 130 and respirations, from 34 to 40. These values remained fairly stationary until the fifth day, when gradual improvement began. On the eighth day, the temperature reached normal, the pulse rate was 90 and respirations, 28. Physical signs and roentgenographic examination showed

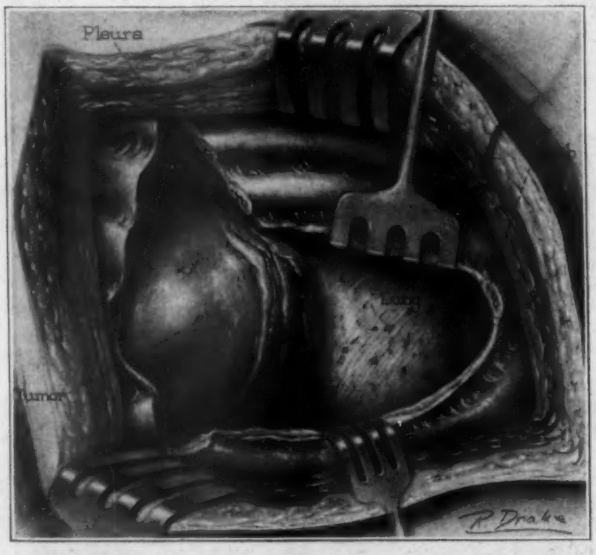

Fig. 17 (case 7).—Intrathoracic neurofibroma of the posterior mediastinum. Extrapleural exposure of the tumor.

evidence of fluid in the pleural cavity, necessitating aspiration on one occasion. The patient's temperature was normal from the nineteenth day, the pulse remained between 70 and 76, and respirations between 20 and 24. She was dismissed from my care one month following operation; the wound was entirely healed and she was feeling well generally. Roentgenographic examination did not afford evidence of fluid in the pleural cavity. Roentgenograms of the thorax two years after operation showed the lungs to be free from disease, and the general condition of the patient was excellent. There was no evidence of return of the tumor (figs. 18 and 19).

This case is of interest because of the various symptoms which were associated with a tumor of this size situated in the posterior mediastinum. Because of the patient's multiple complaints, it was difficult to evaluate

how many of the symptoms were the result of the tumor. Tumors situated in the middle portion of the thorax posteriorly rarely give symptoms until they are of sufficient size to cause marked collapse of the lung. The benign tumors in this area probably are the most silent tumors of the thorax. This is the only case in this group in which it was possible to remove the tumor by extrapleural operation. In this instance, a small area of the pleura was opened because of adhesions to to the tumor. As was noted, pleural effusion occurred postoperatively, necessitating one aspiration. It has been my experience that the pleura has been adherent to the tumors in all cases in which I have operated.

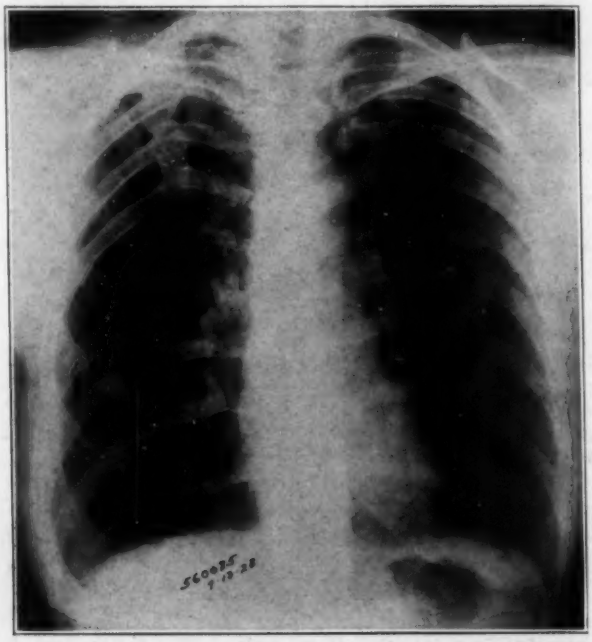

Fig. 18 (case 7).—Roentgenogram taken two years after extrapleural removal of large intrathoracic neurofibroma. Old fracture of the fourth, fifth, sixth and eighth ribs is shown with firm union with absence of the seventh rib posteriorly. Appearance of the lungs is normal.

I do not believe it advisable to attempt extrapleural removal because marked separation of the pleura from the thoracic wall is necessary and usually the pleural cavity ultimately has to be opened.

Case 8.—A married woman, aged 35, was admitted to the clinic on March 19, 1928. The final diagnosis was large left intrathoracic cellular fibroma. The chief complaint was pain in the upper left part of the chest of about nine years' duration. The onset of the complaint began nine years before admission, while the patient was working on a farm, stacking hay and carrying heavy weights. She first had noticed pain in the upper left part of the thorax. It had been periodic

for six years, and usually had been noted following extreme exertion. The pain had become severe, with marked dypnea, and the patient had been confined to bed. At this time a diagnosis of tuberculosis had been made. Four liters of clear fluid had been removed by aspiration from the left pleural cavity. For the next two years the pain had been more or less constant, and more severe on exertion. A year and a half before she came to the clinic, about 2 liters of clear fluid were removed by aspiration from the left side of the thorax. For the year before admission, the pain gradually had extended from the left upper portion of the thorax to the left axilla, left shoulder and left side of the neck. This pain had become progressively worse but could be relieved by hot applications. The

Fig. 19 (case 7).—Two years after extrapleural removal of large right intrathoracic neurofibroma.

dyspnea had become progressively more marked. She had not had cough, expectoration or loss of weight.

Results of general examination were essentially negative except for dulness on percussion and absence of breath sounds in the greater portion of the left lung, with dulness extending beyond the sternum, to the right side of the chest. Urinalysis gave negative results. The hemoglobin was 72 per cent and the Wassermann reaction of the blood was negative. The sputum was negative for bacilli of tuberculosis. Roentgenograms of the thorax revealed evidence of a large intrathoracic tumor involving the upper two thirds of the left side of the thorax, probably primarily benign but now malignant (fig. 20).

Left posterior thoracotomy, with removal of a portion of the seventh rib and section of the fourth, fifth, sixth and eighth ribs, was done April 21, 1928. Transpleural complete removal of the intrathoracic tumor was accomplished. The thoracic cavity was closed without drainage. Intratracheal ether and ethylene anesthesia was used.

On exposing the left pleural cavity, a huge semicystic tumor was found which completely filled the upper two thirds of the thoracic cavity, from the apex to the eighth rib, and pushed the mediastinum to the right. The entire upper lobe of the left lung was collapsed, with partial collapse of the lower lobe. The wall of the tumor was firmly adherent to the pleura, and there was a firm attachment posteriorly, along the line of the spinal column. Most of the tumor was solid, but there were several lobulated cystic areas, a great many of which were ruptured

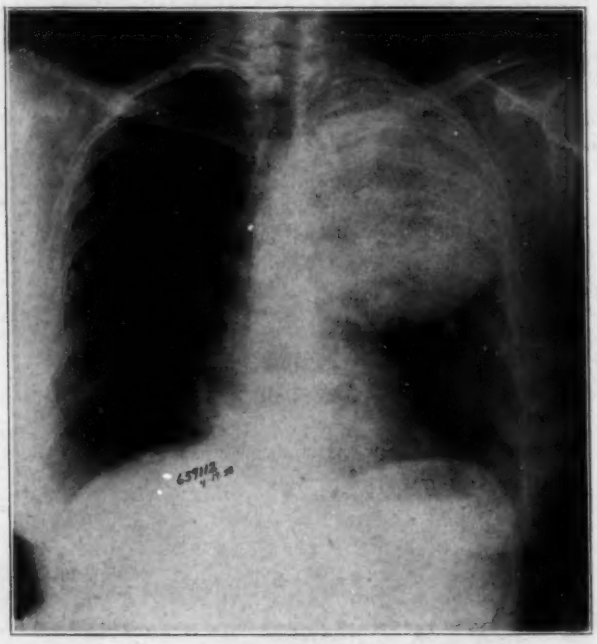

Fig. 20 (case 8).—Large intrathoracic tumor completely filling the entire left upper portion of the thorax to level of the ninth rib posteriorly at time of patient's admission. The trachea is markedly displaced to the right.

during removal and were found to contain about 1,200 cc. of blood-tinged serous fluid. The rupture of these cystic regions reduced the size of the tumor at least half. The entire tumor was removed and the thoracic cavity was closed (figs. 21, 22, 23 and 24).

The operative diagnosis was of a large intrathoracic fibroma completely filling the upper two thirds of the left side of the thorax, extending into the posterior mediastinum and pushing the trachea to the right. There was almost complete compression of the left lung. The mediastinum was pushed to the right, with partial compression of the right lung. Pathologic examination revealed a cellular fibroma, weighing 340 Gm. (fig. 25).

There was considerable shock at the time of operation, with a pulse rate of 140 and a temperature of 102 F. in the afternoon of the first day. The patient was given solution of sodium chloride intravenously immediately after the operation and her reaction was satisfactory. The pulse rate dropped to 110 on the second day. On the fourth day, the temperature was normal and the pulse rate, 94.

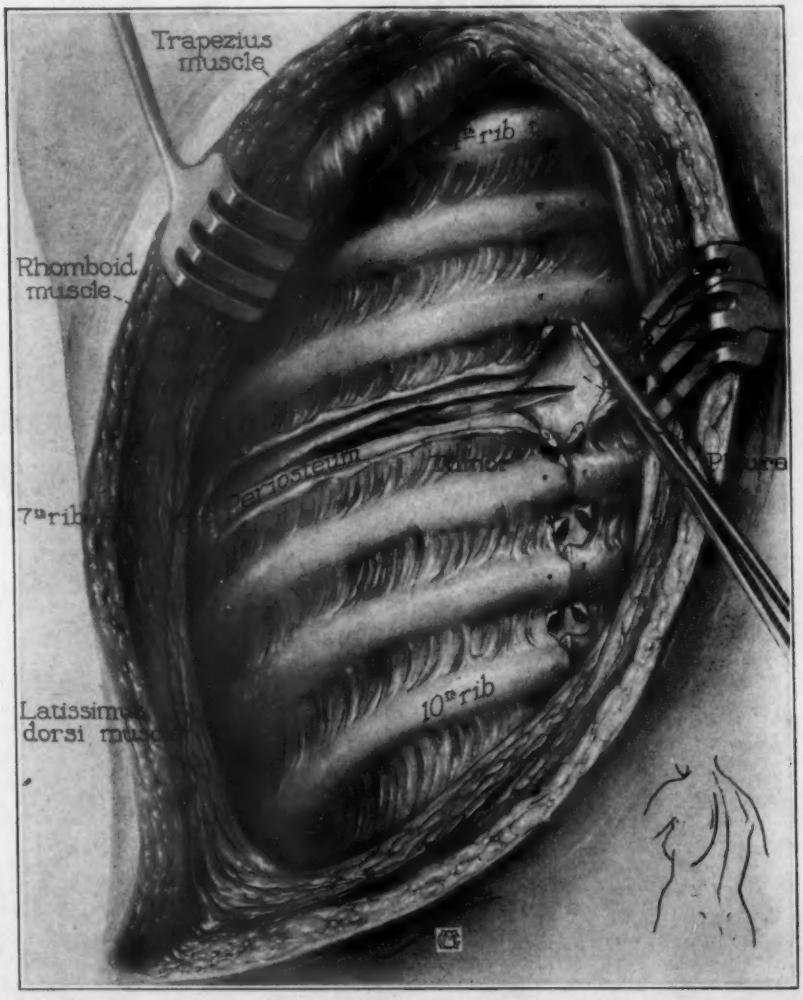

Fig. 21 (case 8).—Insert shows posterolateral incision. Retraction of the scapula forward; resection of the posterior two thirds of the seventh rib. The adjacent ribs were drilled before section; intercostal vessels caught and ligated before section; pleura incised through the posterior periosteum of the resected rib.

Roentgenographic examination of the left pleural cavity revealed fluid which was aspirated on the sixth, eighth and tenth days. Cultures were made of the fluid; growth did not result. On the fourteenth day, fluid again was aspirated from the pleural cavity; 200 cc. was obtained which showed the presence of an

occasional gram-positive coccus. There was gradual expansion of the lung. The patient ran a slight temperature for about a week, and the pleural cavity again was aspirated, with results similar to those obtained previously. On the twenty-eighth day, the temperature dropped to normal and remained practically normal during the remainder of convalescence. The patient was dismissed on the forty-second

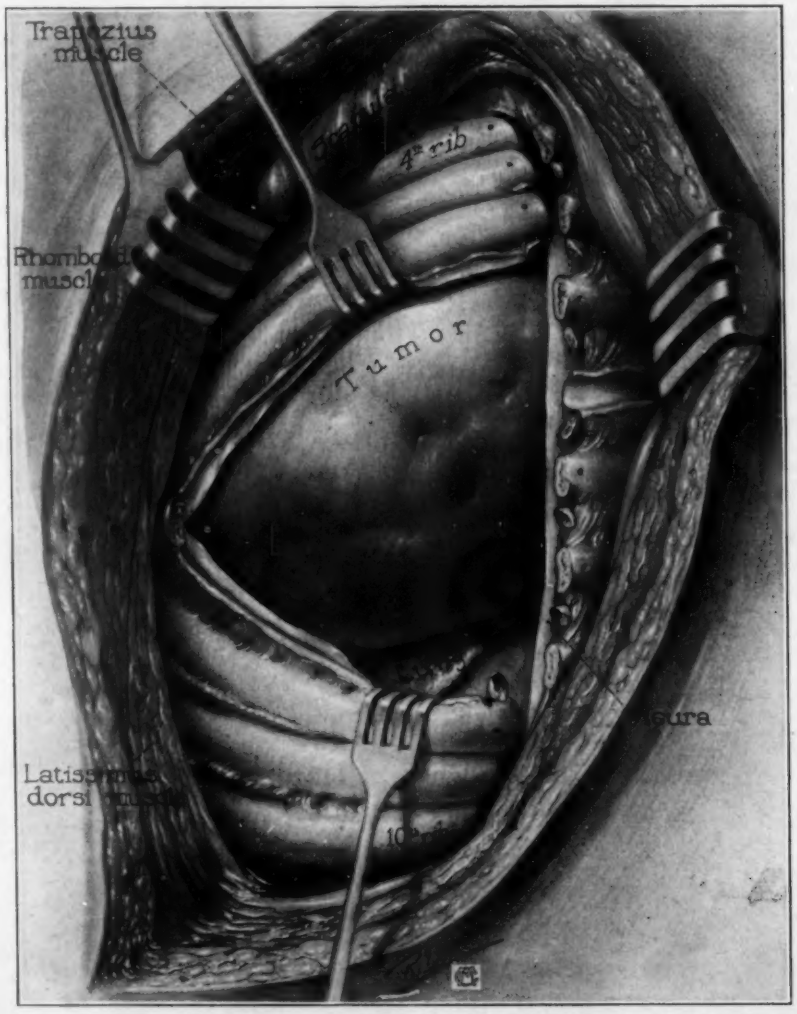

Fig. 22 (case 8).—Section of the fourth, fifth, sixth, eighth and ninth ribs and intercostal muscles. Retraction of the ribs exposing the left pleural cavity. Lower portion of the tumor presenting in the wound. Small portion of collapsed lung can be seen at the lower angle.

day after operation, with the lung completely expanded and with complete relief from symptoms (fig. 26).

The patient returned for observation about six months following the removal of the intrathoracic tumor. Her general condition had markedly improved and

she had gained 15 pounds (6.8 Kg.). She had practically no dyspnea on exertion. Roentgenographic examination showed that the left lung was completely expanded (fig. 27).

The clinical history, in this case, extending over a period of nine years, and the fact that the patient remained in good general condition

Fig. 23 (case 8).—Pleura closed with continuous catgut sutures; cut ends of ribs tied with chromic catgut.

suggested that a benign lesion was present. The progressive symptoms were caused by increasing pressure on the mediastinal structures and collapse of the lung, due to the growth of the tumor. The early diagnosis of tuberculosis had been made because of the removal, by aspiration, of clear fluid from the thorax. This fluid probably was removed

Fig. 24 (case 8).—Rectospinous muscles sutured over the vertical incision making the wound airtight after full reexpansion of the lung.

from the cystic tumor and not from the pleural cavity. The wall of the tumor was covered with pleura; probably the tumor originated from an intravertebral disk in the upper part of the posterior mediastinum. The operative removal was difficult because of the size of the tumor and because of adhesions of the tumor to the surrounding structures. The posterior operative approach was satisfactory, as it usually is in these large tumors, for the opening in the wall of the chest can be enlarged

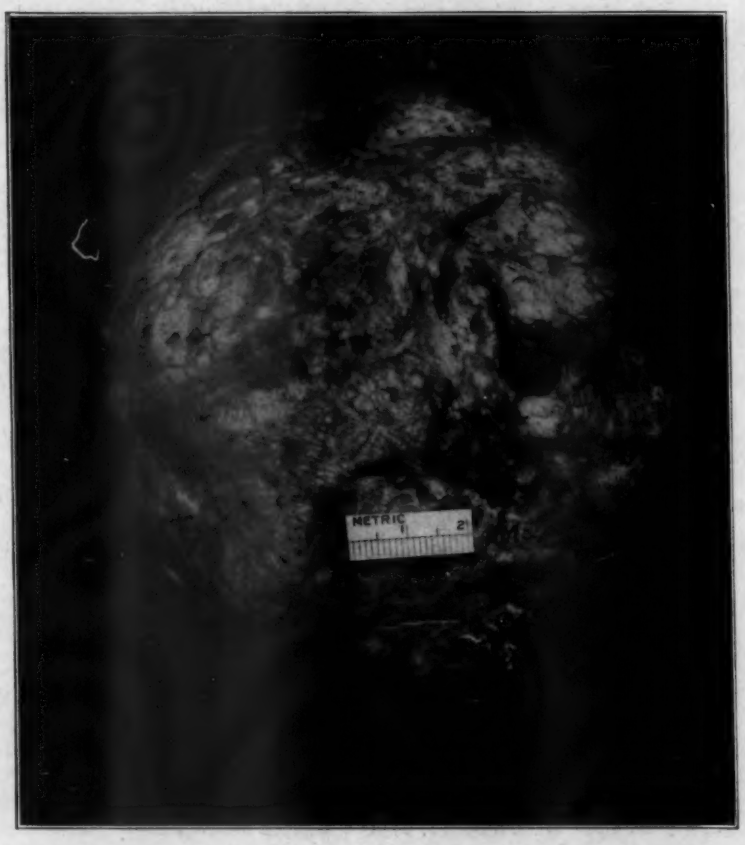

Fig. 25 (case 8).—Large left intrathoracic cellular fibroma.

readily by cutting and retracting the adjacent ribs until sufficient exposure is obtained.

Four years ago I reported before this society a case with anterior removal of an intrathoracic fibrosarcoma which was about half the size of this tumor, but in the same situation. The symptoms were of twenty-four years' duration, which strongly suggested the presence of a benign tumor which had undergone malignant degeneration. The patient was free from symptoms for about a year and a half after operation, when

recurrence developed, and death occurred of a malignant condition two and a half years after the operation. This emphasizes the importance of early diagnosis and operation.

CASE 9.—A man, aged 60, was admitted to the clinic on March 12, 1928. The final diagnosis was a large intrathoracic cellular fibroma of the right side. The chief complaint was of pain in the right part of the chest of three years' duration. About three years before admission the patient first had noticed in the right lower part of the chest, pain which had radiated to the right lumbar region. The pain had been dull at first, had been periodic, but had been progressive and almost constant for the three months before he came to the clinic. He had not had cough

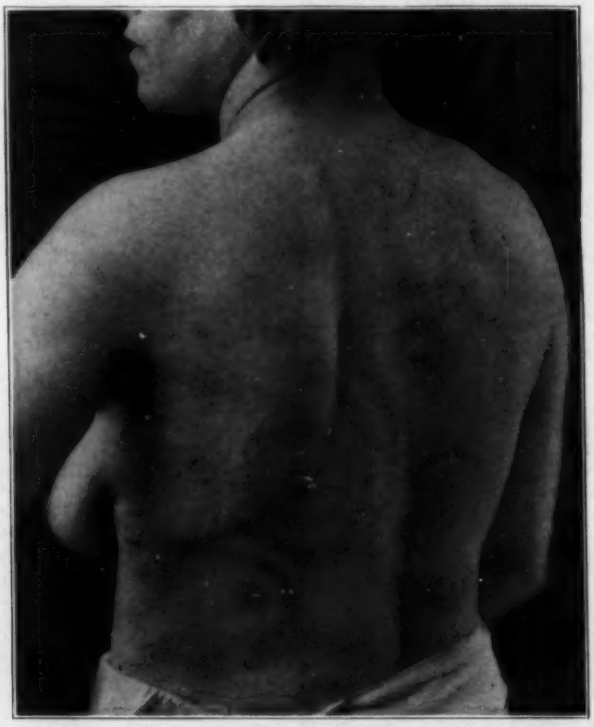

Fig. 26 (case 8).—Wound of left upper posterior mediastinotomy after removal of large intrathoracic tumor weighing 340 Gm. Complete relief from symptoms followed.

or expectoration. There had been marked dyspnea on exertion. Loss of weight had not been noticed. One week previous to admission, the right thoracic cavity had been aspirated and a large amount of bloody fluid had been obtained. A diagnosis of malignant condition of the pleura had been made.

Results of general examination were essentially negative except for decreased breath sounds and dulness to percussion over the posterior lower right part of the thorax. Urinalysis gave negative results. Examination of the blood, including the Wassermann reaction, gave negative results. Roentgenograms disclosed marked increased density of the right lower part of the thorax extending upward

to the level of the second rib. The impression was of intrathoracic tumor, with fluid in the region of the base of the right lung. Fluoroscopic examination showed the diaphragm to be normal in position and function (fig. 28).

Preoperative preparation included right pleurocentesis, with removal of 1,000 cc. of bloody fluid on March 17, 1928. This procedure was repeated on March 28, with removal of 800 cc. of bloody fluid; March 31, with removal of 1,500 cc. of bloody fluid; April 14, with removal of 1,500 cc. of bloody fluid, and on April 18, with removal of 1,200 cc. of bloody fluid. Repeated examinations were made for malignant cells, with negative results, and all fluid sent for culture failed to give a growth.

Right posterior thoracotomy, with removal of about 12.5 cm. of the ninth rib and section of the eighth and seventh ribs at the costovertebral angle, was done

Fig. 27 (case 8).—Roentgenogram taken about six months after transpleural complete removal of tumor and partial resection of the sixth rib and fracture of the seventh, fifth, and fourth ribs on the left. Complete reexpansion of the left lung followed.

April 25. Transpleural complete removal of the tumor was effected. The thoracic cavity was closed without drainage. Intratracheal ethylene and ether anesthesia was used. The right pleural cavity was exposed by incising the pleura along the bed of the partially removed ninth rib. The lower and middle lobes of the right lung were completely collapsed, and there was a large quantity of bloody fluid in the pleural cavity. An elliptical shaped tumor was found filling the entire lower part of the thorax, over which the surrounding middle and lower lobes of the lung were collapsed. The tumor was adherent to the diaphragm as well as to all of the surrounding pulmonary tissue. Dissection by knife was necessary to separate the tumor from the diaphragm and from some parts of the lung. The

tumor also was firmly adherent posteriorly, close to the spine, about the juncture of the tenth rib, and sharp dissection was required at this point. The tumor was completely removed and the pleural cavity was closed (fig. 29).

The operative diagnosis was of intrathoracic cellular fibroma of the lower right part of the thorax, with the tumor arising, apparently, at the juncture of the tenth rib and vertebra. It was adherent to the posterior third of the diaphragm and caused complete collapse of the middle and lower lobes of the right lung to which it was adherent. There was associated bloody pleural effusion. Pathologic examination revealed a cellular fibroma weighing 630 Gm. and measuring 14 by 11 by 10 cm.

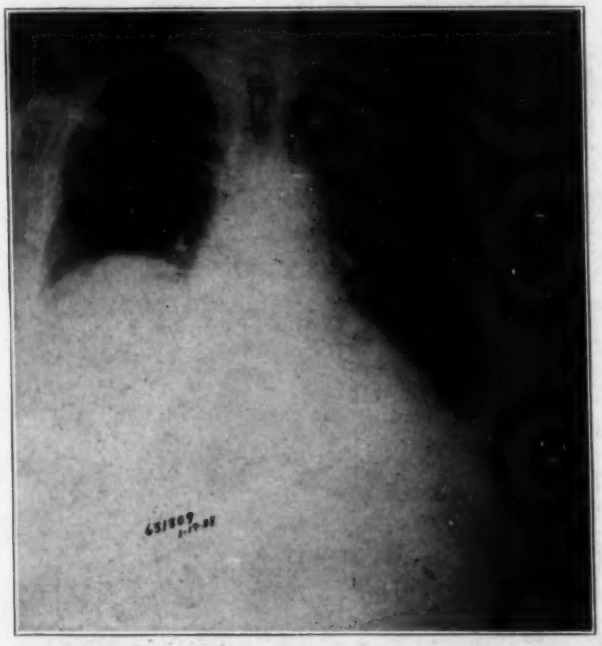

Fig. 28 (case 9).—Roentgenogram taken at time of patient's admission showing marked increased density in right lower thorax to level of second rib, probably an intrathoracic tumor with fluid in right base.

There was moderate shock at the time of operation. On the second day, the temperature was 101 F. and the pulse rate 140. On the fourth day there was a gradual drop of temperature to normal, and of the pulse rate to 110. Fluid was aspirated from the right pleural cavity on the third and sixth days, and on the ninth day a small tube was inserted into the angle of the wound. The cavity was irrigated with a surgical solution of chlorinated soda for a period of three weeks, after which time the tube was removed and the residual pocket was permitted to close by reexpansion of the lung and granulation of the wound. The patient was dismissed in two months from the time of operation. It is now one year since operation; the patient has gained 20 pounds (9 Kg.), and is entirely free from symptoms (fig. 30).

This case is of particular interest because of the age of the patient, and because of the occurrence of a bloody pleural effusion, both of which suggested a malignant lesion. The history of three years' duration and the absence of loss of weight suggested the possibility of a benign lesion, and the patient was placed under observation. The fluid was

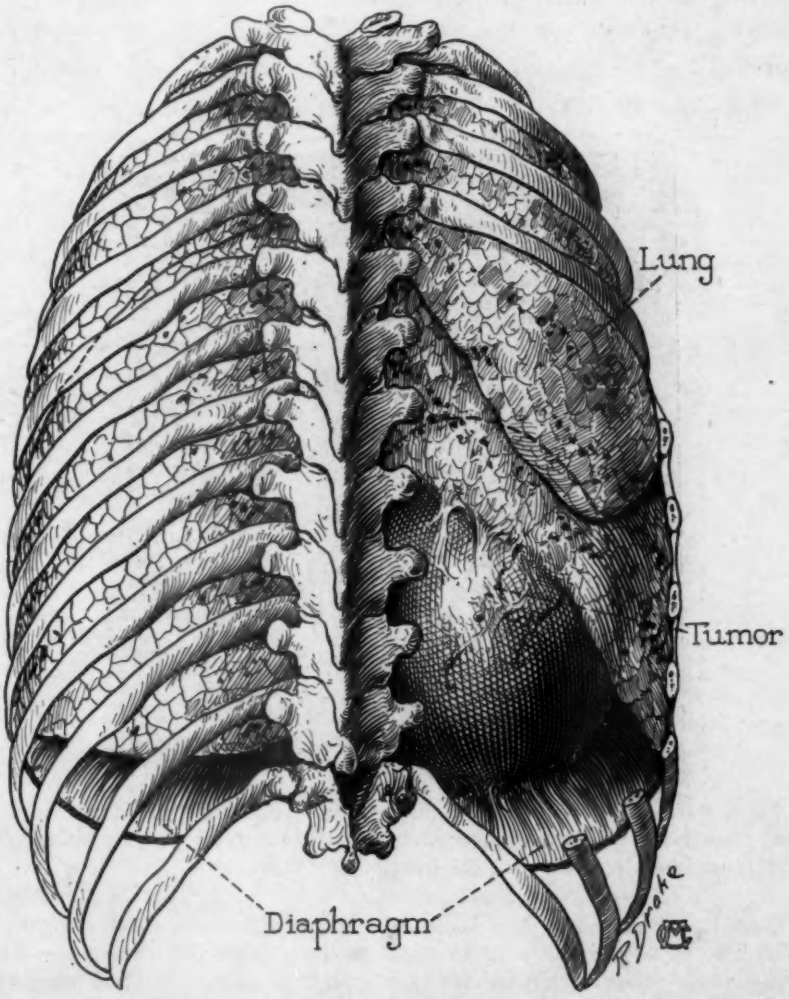

Fig. 29 (case 9).—Large right posterior lower intrathoracic tumor apparently arising at the level of the tenth thoracic vetebra with firm adhesions to the lower lobe of the right lung and diaphragm.

aspirated from the right pleural cavity and a roentgenogram, made immediately after removal of the fluid, showed a large rounded shadow extending above the fluid that remained at the base. This procedure was repeated several times. The removal of the fluid relieved the

dyspnea to a great extent, but did not relieve the pain in the right lower part of the chest. The patient's general condition remained good. It was thought that the tumor was probably benign and operation was advised. Posterior thoracotomy was done, the tumor was removed and microscopic examination showed it to be a fibroma. The immediate convalescence was stormy, but the ultimate result was satisfactory.

This is the only case that I have observed of bloody pleural effusion associated with a benign mediastinal tumor. Intrathoracic operations on patients aged 60 carry great operative risk.

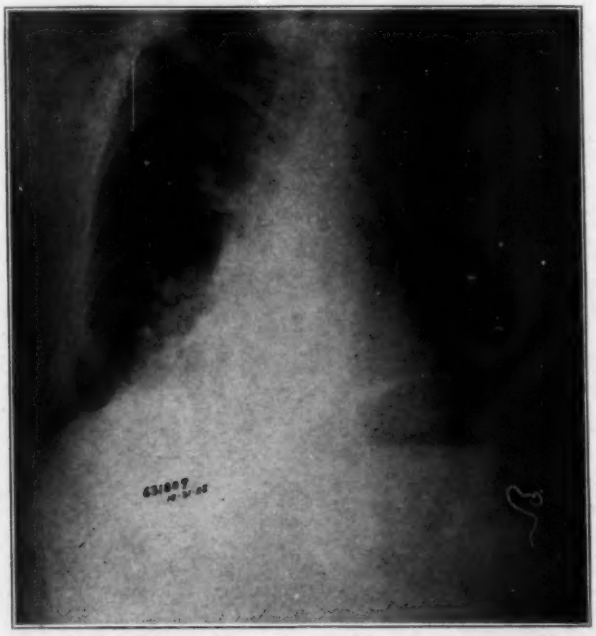

Fig. 30 (case 9).—Resection of the ninth rib; thickened pleura at the right base; lung completely reexpanded; complete relief from symptoms six months after transpleural removal of large intrathoracic fibroma.

Case 10.—A married woman, aged 38, was admitted to the clinic on April 2, 1929. The final diagnosis was right intrathoracic neurofibroma in the lower right portion of the posterior mediastinum originating at the juncture of the ninth and tenth thoracic vertebrae. The chief complaint was of a dull aching pain in right costovertebral angle. For several years the patient had had attacks of swelling in the right upper quadrant of the abdomen which had lasted from a few minutes to an hour. These attacks had been associated with dull, aching pain at the site of the swelling along the right costal margin. Pain also had been felt at the right costovertebral angle, posteriorly. The pain never had been severe, usually had been more noticeable at night, had been sufficient to keep the patient awake, and on a few occasions after she had been asleep she had been wakened because of the pain. There had been moderate dyspnea on exertion. The patient had not had

cough or expectoration, and there had not been any relationship between the pain and the taking of food. Loss of weight had not been noticed.

The results of general examination were essentially negative. Urinalysis was negative. The combined intravenous phenolsulphonphthalein test of renal function gave a return of dye of 50 per cent. The hemoglobin was 56 per cent and leukocytes numbered 6,400 per cubic millimeter. Slight anisocytosis and poikilocytosis was present. The Wassermann reaction of the blood was negative. Analysis of gastric content showed total acidity of 54 and free hydrochloric acid of 26 in terms of tenth normal sodium hydroxide. The total quantity of gastric content was 80 cc. Roentgenograms of the stomach were negative and examination of the gallbladder revealed normal function. Roentgenograms of the thorax disclosed a circumscribed, round tumor in the right posterior part of the thorax, at

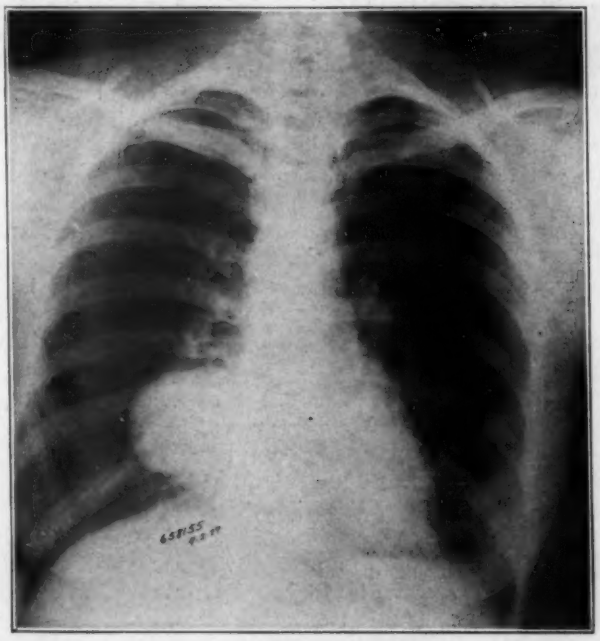

Fig. 31 (case 10).—Round, lobulated, circumscribed tumor in the right lower thorax, posteriorly at the level of the ninth and tenth ribs at time of patient's admission.

the level of the ninth and tenth ribs, posteriorly (fig. 31). The stereoscopic examination showed the tumor to be posterior to the right border of the heart and to the right lung. Fluoroscopic examination showed the tumor to be nonpulsile. Lateral views revealed a rounded tumor in the posterior mediastinum, at the level of the ninth and tenth thoracic vertebrae. The examination of the spinal column disclosed a slight destruction of the right side of the ninth vertebra.

Right posterior thoracotomy, with removal of portions of the ninth rib and section of the seventh, eighth and tenth ribs, was done April 17, 1929. Complete transpleural removal of the posterior mediastinal tumor was accomplished. The thoracic cavity was closed without drainage. There was a large, cystic tumor, 14 by 8 by 6 cm. situated at the level of the ninth and tenth thoracic vertebrae,

posteriorly, and apparently originating at the juncture between these two vertebrae at a point where there was slight erosion of the spinous processes. The tumor extended over the bodies of the vertebrae and forward to the angle of the ninth and tenth ribs. The pleura was under such great tension that the capsule was ruptured during its removal, with escape of about 250 cc. of brownish, clear fluid; this reduced the tumor to about half its original size. The rest of the tumor consisted of solid tissue, and was completely removed, with the overlying pleura. The lower lobe of the lung was partially compressed by the tumor and the surface of the lung was adherent to the diaphragm. After complete removal of the tumor, the cut seventh, eighth and tenth ribs were sutured with double strands of chromic catgut and the incision of the pleura, along the bed of the ninth rib, was closed with plain catgut. The erector spinae muscles were sutured over the angles of the ribs, and the right side of the thoracic cavity was closed. The patient's condition was satisfactory at the completion of the operation. The blood pressure was 105 systolic and 80 diastolic. The pulse rate was 110.

The operative diagnosis was of right intrathoracic neurofibroma situated in the lower part of the posterior mediastinum and originating at the juncture of the ninth and tenth thoracic vertebrae. Pathologic diagnosis was of degenerating neurofibroma.

During the patient's convalescence it was necessary to aspirate the right pleural cavity on several occasions. The first aspiration showed a few colonies of gram-positive cocci on culture, and on the tenth day a tube was inserted into the pleural cavity for drainage and irrigations. There had not been any formation of definite pus, but because of the presence of a daily fever, I thought it advisable to institute intracostal closed drainage. The temperature dropped to normal about four days after insertion of the tube. She has now been dismissed from the hospital and her condition is satisfactory.

CASE 11.—A man, aged 38, was admitted to the clinic on July 14, 1928. The final diagnosis was primary carcinoma of the right lung firmly adherent to the wall of the chest and clavicle and infiltrating into the mediastinum. The chief complaint was pain in the upper right part of the chest, of nine months' duration. The patient had been well until nine months before admission when he first had noticed a sharp pain between the shoulder blades which radiated down the right arm. A diagnosis of neuritis had been made and the chest had been strapped; this had relieved the pain. Five months before he came to the clinic, following exertion, he had noticed the same type of pain throughout the upper part of the chest. This pain had persisted intermittently up to the time of his admission. Tonsillectomy had been performed under local anesthesia about three months before admission but the pain had not been altered, and since had become severe, particularly at night. The pain at the time of admission was of a burning stinging type, and was situated, at times, in the right upper part of the chest and at other times between the shoulder blades and in the upper part of the right arm. About one month before he came to the clinic he had noticed contraction of the pupil of the right eye, with ptosis of the right lid. It was thought that the symptoms might be caused by a cervical rib and a roentgenographic examination was made which revealed a large tumor in the right upper portion of the thorax. He had lost 15 pounds (6.8 Kg.) during the last three months.

General examination revealed Horner's syndrome on the right side. The right pupil did not dilate when cocaine was administered and the right palpebral fissure was narrower than the left. The right arm was warmer than the left, and the muscular tone in this arm was less than in the left. Dulness was noted over the upper right part of the thorax, between the scapulae, and breath sounds were

impaired. The hemoglobin was 64 per cent and the leukocytes numbered 6,200 per cubic millimeter. The Wassermann reaction of the blood was negative. Roentgenograms of the thorax revealed evidence of a tumor of the upper lobe of the right lung anteriorly, extending to the level of the second rib in front. The tumor was thought to be benign (figs. 32 and 33).

Upper right posterior thoracotomy, with removal of a portion of the sixth rib and section of the fifth and fourth ribs at the costovertebral angle was done July 25, 1928. Transpleural exploration of tumor with removal of a specimen for diagnosis was carried out. Intercostal closed drainage was instituted, with insertion of number 20 French catheter through the ninth intercostal space, in the posterior axillary line. Intratracheal ethylene anesthesia was used. When the pleural cavity was opened, a large tumor was found which involved practically

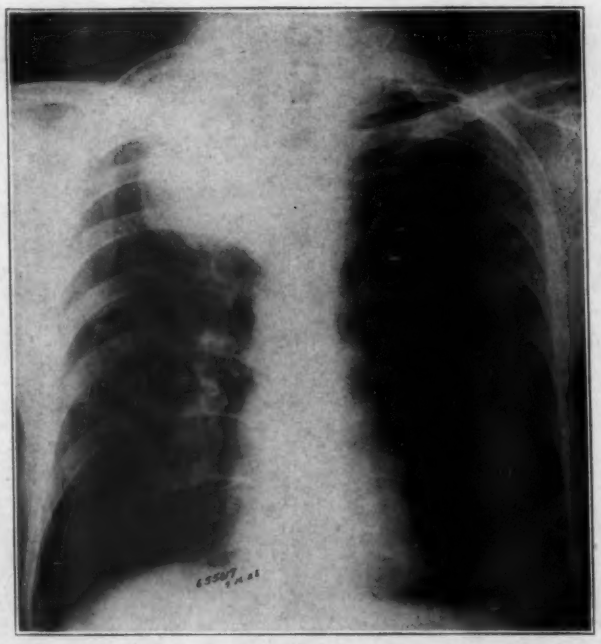

Fig. 32 (case 11).—Tumor in the upper right lobe anteriorly extending to the level of the second rib in front (benign?) at time of patient's admission.

the entire upper lobe of the right lung. The tumor was centrally situated, with a small portion of pulmonary tissue entirely encircling it. This pulmonary tissue, however, was atelectatic and did not become inflated on inspiration. The tumor was adherent to the posterior thoracic wall, from the first to the fifth ribs, and was adherent to the first rib throughout its entire extent, and to the second rib anteriorly. Because of its infiltration into the thoracic wall, it was thought to be malignant and a specimen was removed from its attachment to the posterior thoracic wall at about the level of the fourth rib. This proved to be an adenocarcinoma of the lung. Because of the marked invasion of both the anterior and the posterior wall of the chest, the tumor was considered to be inoperable. The invasion of the anterior thoracic wall probably produced the Horner's syndrome. The cut ribs were tied with chromic catgut and the incision was completely closed.

The operative diagnosis was primary carcinoma involving the entire upper lobe of the right lung, firmly adherent to the upper right part of the thoracic wall, both anteriorly and posteriorly, and involving the lower cervical sympathetic ganglion producing Horner's syndrome. Pathologic examination revealed adenosarcoma, graded 3.

Immediate convalescence was uneventful and the patient was dismissed from my care on the twenty-fourth day. I was informed, by a letter from the patient's wife, that he died, Nov. 5, 1928. His symptoms had become progressively worse until death.

The relatively short duration of symptoms, the severity of the pain and the rapid evolution of symptoms, with loss of weight, suggested that

Fig. 33 (case 11).—Horner's syndrome on the right; inoperable primary carcinoma of the upper lobe of the right lung.

the lesion was malignant. The presence of a Horner's syndrome and the fact that a relatively small tumor was shown by roentgenogram, indicated an infiltrating type of lesion. However, the rounded shadow shown by the roentgenogram suggested a possible benign lesion. Operation was advised because of the possibility of the condition being benign and in the hope that if it were malignant it would be sufficiently localized to the upper lobe so that lobectomy would be possible. The tumor was explored through a posterior thoracotomy incision and was found to be an extensive carcinoma of the upper lobe of the lung, infiltrating into the surrounding wall of the chest.

I have operated in three cases of intrathoracic tumor presenting Horner's syndrome at the time of operation. In each instance, the tumor has been malignant; in two cases, it was inoperable, and in the third case, it was removed, but the Horner's syndrome persisted without improvement. This patient died two and a half years after operation from recurrence.

CASE 12.—A man, aged 41, was admitted on June 20, 1927. The final diagnosis was intrathoracic sarcoma attached to the second and third ribs at the articulation with the vertebrae and infiltrating the upper lobe of the left lung, probably originating in the second rib. The chief complaint was of pain in the left part of the chest of six months' duration. Six months before admission, the patient first had noticed pain in the left part of the chest. It had appeared, for the most part, in the evening and had disappeared at bedtime. The pain gradually had increased in frequency and intensity and had been constant for three months previous to admission. It had been situated more in the precordial region and had been sharp and shooting in character, radiating in all directions in the left side of the chest. It had become worse with the patient sitting or standing without support to the chest, as in reclining or leaning against the back of a chair. The pain had been more severe on deep breathing. Following an attack of influenza one year previously, the patient had had persistent cough and blood-streaked sputum. Tuberculosis had been diagnosed and he had been sent to Colorado, where he had been informed that the condition was not tuberculosis. Soon after he had gone to Colorado, the coughing and expectoration had ceased and the pain had become more severe. Marked numbness in the left hand, which radiated to the left elbow, had appeared. He had lost 15 pounds (6.8 Kg.) in six months.

The results of general examination were essentially negative, except for increased breath sounds over the upper lobe of the left lung. The hemoglobin was 72 per cent, erythrocytes numbered 4,500,000 and leukocytes 7,600 per cubic millimeter. The Wassermann reaction of the blood was negative. Roentgenograms of the thorax revealed evidence of a tumor in the upper lobe of the left lung, extending to the level of the second rib anteriorly. The tumor was thought to be benign (fig. 34).

Left upper posterior thoracotomy, with resection of 15 cm. of the fourth rib, was done on July 7, 1927. Transpleural removal of intrathoracic tumor was effected. The thoracic cavity was closed without drainage. Intratracheal ether and ethylene anesthesia was used.

The left side of the thorax was opened through a curved incision, extending around the scapula parallel with the spinal column. A portion of the fourth rib was then removed and the pleura was opened through the posterior periosteum of the rib and exploration of the upper part of the thoracic cavity was carried out. A large tumor was found, which was attached at the costovertebral angle posteriorly, at the level of the juncture of the second and third ribs with the spinal column and extending down to the fourth rib. In separating it from its attachment to the ribs and vertebrae, the capsule was ruptured. It contained broken-down granular tissue which was soft and could be scooped out with the fingers. The tumor had infiltrated into the upper lobe of the left lung in which it had formed a cavity about 6 cm. in diameter. The cavity was completely filled with this broken-down, granular, necrotic material.

The operative diagnosis was of intrathoracic sarcoma attached to the second and third ribs at the vertebral articulation and infiltrating into the upper lobe of the left lung, probably originating in the second rib. Pathologic examination revealed a sarcoma, graded 3, with many giant cells.

Moderate shock followed the operation. Subcutaneous emphysema was noticed about the chest and neck. On the second day this gradually became more marked, involving the entire chest, neck, face and the arms and extending into the fingers and remained about the same for forty-eight hours. The patient was unable to open his eyes and had some difficulty in swallowing and breathing. During this period oxygen was administered by means of a portable oxygen cabinet and after forty-eight hours the emphysema gradually began to disappear and had entirely disappeared from the face and neck by the ninth day, and from the upper part of the

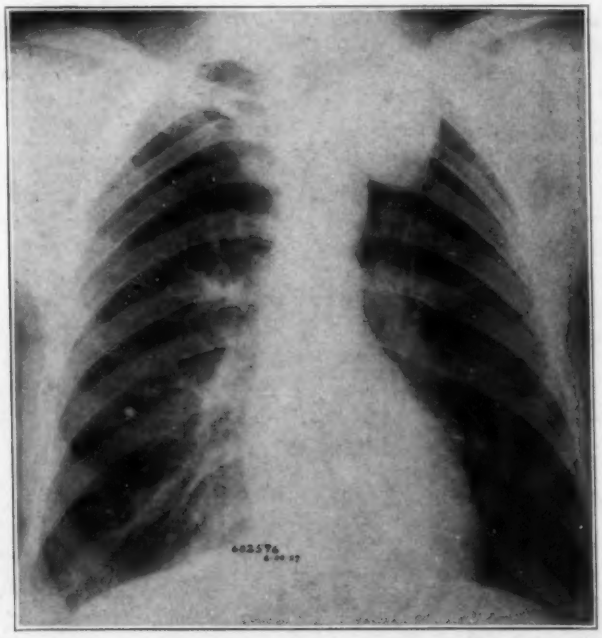

Fig. 34 (case 12).—Tumor of the upper lobe of the left lung extending to the level of the second rib anteriorly (benign?) at time of patient's admission.

chest by the twelfth day. He was dismissed from my care on the fifteenth day after operation, with the wound entirely healed. In reply to a questionnaire sent Jan. 23, 1928, I was informed that the patient had died Oct. 28, 1927.

The short history, and the onset, with severe pain rapidly increasing in severity, and the late development of cough, was more suggestive of a malignant condition than of tuberculosis. The cough probably was the result of the sarcoma infiltrating the lung and causing many small bronchial fistulas. The emphysema following the operation was extensive and probably was caused by the multiple small bronchial fistulas in the bed of the tumor. The condition gradually improved by administra-

tion of oxygen which was continued until the absorption of air permitted normal breathing. Slight surgical emphysema of the tissues around the site of operation on the thorax is not uncommon and rarely persists more than from forty-eight to seventy-two hours.

SUMMARY

Twelve cases of intrathoracic tumors are reported here and five cases have been reported previously. This makes seventeen cases in which transpleural operation has been done.

In fifteen cases the tumor was completely removed, in one case by a two-stage operation and in fourteen cases by a one-stage operation.

In two cases exploration only was performed. The condition was proved to be a high grade malignancy by microscopic examination of tissue removed and the lesion was inoperable because of the extensive infiltration into the wall of the chest and mediastinal structures.

In the entire series of seventeen cases there was one operative death. Death occurred on the seventh day following operation from cerebral embolism. This gives an operative mortality of 5.5 per cent.

The tumor was malignant in eight of the cases, in two of which the tumor was so extensive that exploration only was possible. In the remaining six cases the tumor was removed completely. In two cases, one of malignant endothelioma and one of osteogenic sarcoma, the patients died from metastasis in the first year after operation. One patient with fibrosarcoma died from metastasis two years and two months after operation. Two patients are living. One of these had malignant endothelioma, and a portion of the diaphragm and thoracic wall was resected with the tumor; there is no evidence of recurrence in this case one and a half years after operation. The other living patient had osteofibrosarcoma; there is no evidence of recurrence four years after operation. The remaining patient, who had squamous cell epithelioma, died following operation.

I believe that the operative results in this group of malignant cases justify a more optimistic view than generally is taken in these cases and that they emphasize the importance of early diagnosis.

In the nine benign cases, the tumor was completely removed by an operation in one stage. There was no operative mortality and all patients apparently are cured. It is this group of benign cases that is most gratifying from the surgical standpoint. As it often is impossible definitely to determine the operability, or the type of tumor, by present methods of diagnosis, and, as there is reason to believe that a benign tumor will undergo malignant change as shown in two cases here presented, I believe that in all cases of intrathoracic tumor exploration should be carried out unless the clinical evidence is that a hopeless inoperable condition exists.

THE TREATMENT OF SOME UNUSUAL AND DIFFICULT CASES OF EMPYEMA

CHARLES D. LOCKWOOD, M.D.
PASADENA, CALIF.

The problem of chronic empyema still presents many difficulties, and there is no standardized procedure applicable to all cases; each must be individualized. I believe, however, that every case of non-tuberculous empyema can be soundly healed by judicious and persistent treatment.

The first step in every long-standing case of pleural suppuration should be a most painstaking study to determine the location and dimensions of the empyema cavity, the expansibility of the lung, the existence of pleurobronchial fistulas and the nature and virulence of the organisms. The general condition of the patient should also be considered in deciding on the extent and type of operation to be undertaken. Most of the patients suffering from long-standing empyema have damaged kidneys and hearts and do not tolerate long and shocking operations. I formerly used Beck's paste to outline the cavity for roentgen study, but since the introduction of iodized oil I have found this medium less toxic and equally efficient. A stereoscopic roentgenogram is taken in the anteroposterior position and one or more in the lateral position.

Many patients come to California and the Southwest with chronic discharging sinuses or wearing drainage tubes in empyema cavities of long standing. These patients are sent in the hope that the climate and life in the open air will heal their chests. They have usually undergone two or three operations and have finally been condemned to wear drainage tubes indefinitely. It is often difficult to gain the confidence of these chronic sufferers and to induce them to make another effort to obtain healing. Many of the cavities will heal promptly if only the tube is removed and left out, but as the patients have worn the tubes for months or years, they are loth to part with them and are often terror stricken at the suggestion.

In addition to the number of cavities that will heal on removal of the tube and daily cleansing of the cavity, there is another large group in which the drainage is poorly placed or inadequate; often there is a residium of from 4 to 6 ounces (118.4 to 178 cc.) of pus in the bottom of the cavity which drains intermittently or only when the patient is recumbent. A large percentage of these can be healed by adequate dependent drainage and frequent irrigation with surgical solution of chlorinated soda (Dakin's solution).

Before any extensive operation is undertaken to obliterate an old empyema cavity, thorough drainage is secured and the patient's resistance raised by eliminating sepsis. After all the simple measures have been tried, however, and the resistance raised to the maximum, a small group of cases remains which require some radical surgical procedure. I wish to report briefly five such cases and to illustrate the method employed in their treatment.

REPORT OF CASES

CASE 1.—A. B., aged 23, came to California with a discharging sinus of three years' duration. The empyema followed pneumonia. It was drained by a simple rib resection. After more than two years of drainage, another operation was performed, five ribs being resected. There was some improvement, but the sinus persisted. The patient came to California hoping to be cured by the climate, and it was then that I first saw him. Roentgenograms taken at this time, after the injection of bismuth paste, revealed a cavity in the posterolateral aspect of the chest, about 6 inches (15.2 cm.) in length and 1 inch (2.5 cm.) in width. It was separated from the partially expanded lung by a dense membrane. The cavity extended upward and downward about equidistant from the constricted opening in the wall of the chest. A second injection of bismuth paste two weeks later showed the cavity almost double the size it was on first examination. When completely filled, foul smelling pus would well up from the bottom of the cavity. Since there was no improvement, operation was decided on.

First Operation.—The ninth, tenth and eleventh ribs were resected in the posterior axillary line, exposing the bottom of the cavity which rested on the diaphragm. Great improvement followed this improved drainage, but the sinus continued to discharge after prolonged drainage and irrigation with surgical solution of chlorinated soda. After six months' treatment, a second operation was done.

Second Operation.—The cavity was exposed by resection of the previously removed ribs. The thickened pleura was excised, and dense bands of adhesions were divided. The lung was liberated by decortication. All communicating sinuses were obliterated. Prolonged drainage and irrigations with surgical solution of chlorinated soda again failed to secure healing. After eight months the sinuses still persisted.

Third Operation.—The cavity was widely exposed. Decortication of the lung was performed but it would not expand. Two large pedicled skin flaps, one above and one below, were dissected up from the wall of the chest, turned into the cavity and sutured to the thickened visceral pleura; the chest was left widely opened and packed with iodoform gauze. The cavity was packed daily, and rapidly granulated. The skin was pushed in from the edges of the skin flaps, and in about six months the cavity was entirely lined with epithelium. All discharge had ceased, and the patient was restored to perfect health. He has remained well up to the present time, four years after the last operation.

CASE 2.—Dorothy H., aged 23, had pneumonia at the age of 11, followed by empyema. Drainage was performed. The sinus healed and remained closed for one and one-half years, when the cavity refilled; it was again opened. After this operation, it remained healed for three years. The sinus then reopened and has alternately opened and closed at periods varying from three or four months to a year. She had been operated on five or six times with short periods of relief. In 1922, six months before I saw her, after a brief closure, she suddenly

began to expectorate foul pus. She continued to expectorate 8 ounces (236 cc.) daily, with intermittent drainage from a sinus in the left side at the level of the sixth rib. Her general condition was fairly good, but she was harassed by a constant cough and was offensive to every one. Four operations were required to cure her.

First Operation.—The rib was resected at the site of the old sinus. A large empyema cavity was exposed with a Tuffier rib spreader. Thick cicatricial mem-

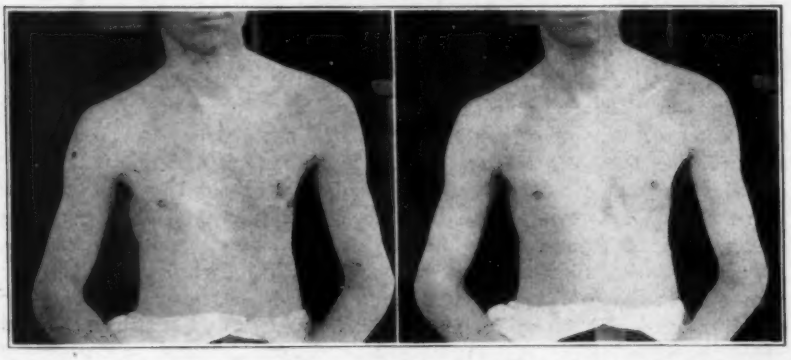

Fig. 1 (case 1).—Chest development after operation, viewed stereoscopically.

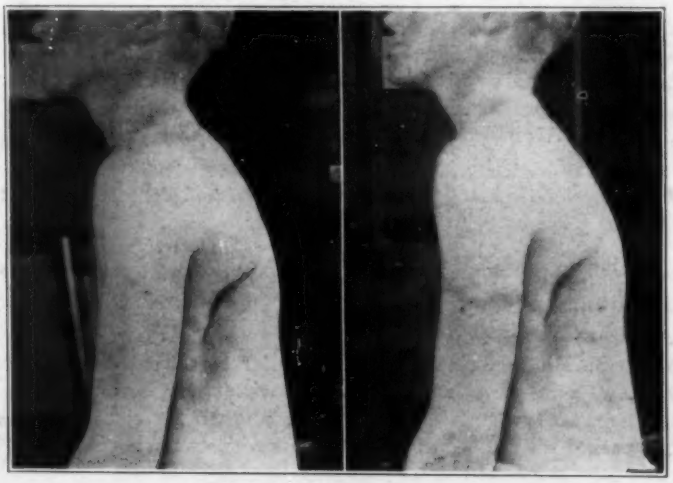

Fig. 2 (case 1).—Healed wound, viewed stereoscopically.

brane covering the lung was incised and partially removed, liberating the lung at the site of the pleurobronchial fistula. A pucker string of chromic catgut was placed about the fistulous opening. The pleurobronchial fistula remained closed and the patient's cough ceased, but the empyema cavity continued to discharge. Two months later, another attempt was made to close the sinus.

Second Operation.—Five ribs and the angle of the scapula were resected. The cavity was widely exposed. The thickened pleura was dissected off of the lung as far as possible. The cavity extended up to the apex of the lung and was inaccessible.

Three large pedicled skin flaps were implanted into the bottom of the cavity; the chest was left wide open and packed with iodoform gauze. After the operation, the patient rapidly improved and gained in weight. The cavity was dressed for many months, and it was necessary to do two subsequent operations with implantation of skin flaps to secure complete epithelization of the visceral pleura. The patient has now been well for four years and is pursuing her profession as a teacher of art.

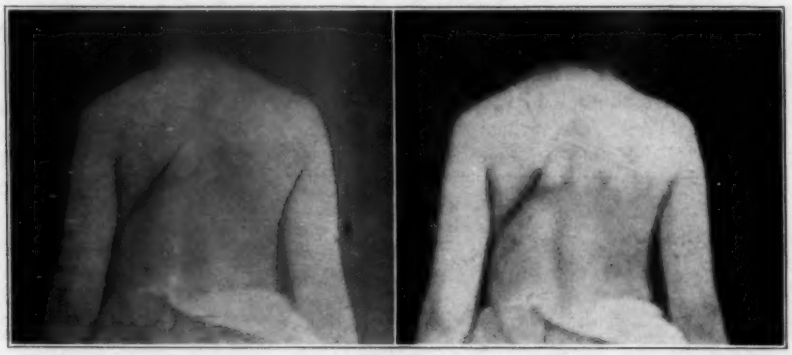

Fig. 3 (case 2).—Incision to reach apex of cavity, viewed stereoscopically.

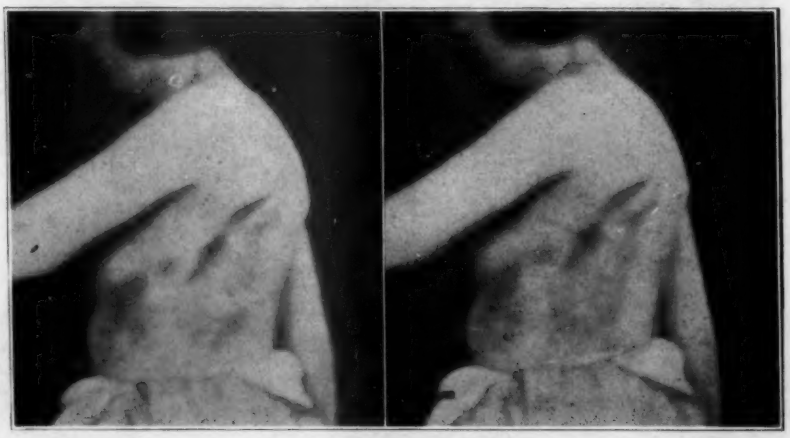

Fig. 4 (case 2).—Healed scar, viewed stereoscopically.

CASE 3.—Mrs. M. C. had empyema secondary to abscesses of the lung. She was referred by Dr. C. C. Browning of Los Angeles for an abscess of the left lung. Six years previously she had suffered from tuberculosis of her right lung, which healed. The development of the abscess can be followed in the x-ray films from its inception until its rupture into the pleural cavity, with the complete filling of the pleural sac with pus. The pus finally broke through into a bronchus, and the patient expectorated from 4 to 6 ounces of fetid pus daily. She was septic and emaciated. The first operation, done in Tucson, Ariz., consisted of

the resection of the eighth rib in the posterior axillary line and the drainage of a thick-walled abscess the size of a hen's egg in the left lower lobe. Improvement followed, but there was a continuous discharge of foul pus, by mouth and through the drainage tube. There were periodic "floodings" of pus, when several ounces would discharge simultaneously through the bronchial fistula by mouth and through the drainage tube. Following these periods, the temperature would drop and the general condition would improve.

Second Operation.—The seventh rib was resected from the costocartilaginous junction to the costovertebral angle. The cavity in the lower lobe was exposed. It was found to consist of several compartments, the uppermost of which communicated by a funnel-shaped opening with a much larger cavity in the upper lobe. The latter occupied almost the entire upper lobe and communicated with a bronchus. These observations explained the periodic floodings of pus. A large

Fig. 5 (case 5).—Front and side views after healing of sinus.

drainage tube was passed through the lower abscess into the upper one, which gave perfect drainage. Rapid improvement followed with greatly diminished expectoration. The sinus of the chest persisted.

Third Operation.—The third operation was performed at the Pasadena Hospital. The lung was freed from the wall of the chest. The fistula was dissected out, swabbed with 2 per cent gentian violet in 70 per cent alcohol and closed with a pucker string of chromic catgut. The chest was closed, with a penrose drain inserted in the posterior angle. The sinus of the chest healed. The patient continued to expectorate 1 or 2 ounces (20 or 60 cc.) of pus daily, with occasional exacerbations of temperature. She regained her normal weight, married and gave birth to a healthy baby. She continued to have periodic attacks of fever with increased sputum. X-ray films taken after the injection of iodized oil revealed a persisting abscess in the left lower lobe.

Fourth Operation.—Thoracoplasty was performed, with resection of the fifth to the tenth ribs. The patient has further improved, but still expectorates from 30 to 60 cc. of sputum daily with an occasional rise in temperature. She is practically well and attends to her household duties, but further collapse of the lung will be required to obliterate the old abscess cavity.

CASE 4.—C. F., a man, had interlobar empyema following lobar pneumonia. He first presented a simple effusion which became purulent after two weeks of normal temperature. Closed drainage with a catheter gave temporary relief with normal temperature. In two weeks the temperature again rose to 104 F. X-ray films showed an interlobar collection of pus at the level of the sixth rib. This was drained by resection of the seventh rib in the anterior axillary line. The x-ray film showed the tube in the abscess with a new abscess forming higher up to the inner side of the apex of the lung and near the mediastinum. The temperature, which had dropped to 101 F., again began to rise, and another x-ray picture one week later showed a well developed abscess near the mediastinum.

The eighth rib and a portion of the seventh were resected. The chest cavity was widely exposed so that the hand could be passed up over the apex of the lung to the mediastinal abscess. Two ounces of fetid pus was evacuated, and a large tube introduced. After this operation, the patient improved rapidly; the temperature returned to normal and he made a complete recovery.

CASE 5.—H. L. A., a man, while in the army in France, in 1918, suffered from acute pleurisy with effusion. He recovered from this condition, and after six weeks was sent to the front. He was wounded. Several fragments of shell perforated the right thoracic cavity, and one fragment entered the left pleural cavity. This fragment was thought to have entered the pericardial sac, and a pericardotomy was done. The fragment was found to be posterior to the pericardium. Empyema developed on the right side. This was drained. The patient was in bed for twenty months and was in a critical condition when he was brought back to the United States. Tubercle bacilli were reported to be present in the sputum during his stay in the army hospital. A bronchial fistula developed and drainage continued from a sinus in the posterior axillary line at the level of the tenth rib on the right side. Another sinus anterior and a little above the main one also drained intermittently. On the left side the apex beat of the heart could be seen and felt at the level of the sixth rib, which had been resected. The patient was greatly emaciated and could get about with difficulty. The ribs on the right side from the fifth to the eighth were overlapping, firmly ankylosed and almost perpendicular. X-ray films made after injection of iodized oil into the sinus showed a cavity 2 by 4 cm. communicating with a similar cavity, more external. The iodized oil could be seen entering a bronchial fistula, from which it was aspirated into the left lung which appeared normal.

The fifth, sixth, seventh and eighth ribs, which were ankylosed to one another and to the angle of the scapula, were resected in one piece by means of a Gigli saw. This permitted the cavity to collapse. Both the sinuses and the bronchial fistulas closed promptly and have remained closed. The patient's general condition is much improved.

EMPYEMA

TREATMENT BY TIDAL IRRIGATION AND SUCTION *

DERYL HART, M.D.
BALTIMORE

A survey of the treatment for empyema by continuous tidal irrigation [1] and supplementary suction for the past eighteen months [2] has shown that this method can be used in the presence of practically any type of organism; that it is satisfactory for patients of all ages; that it works best with a trocar thoracotomy but can be adapted for use with patients having a resection of the ribs; that many patients with chronic empyema can be cured without mutilating operations; that bronchial fistulas close within a few days; that the period of convalescence is shortened; that the mortality is relatively low, and that no patient has left the hospital with a draining sinus. The treatment has also simplified the postoperative care, eliminated the difficult and painful dressings, removed the necessity for special exercises and blowing of bottles to give expansion of the lung and chest, and decreased the amount of bacterial soiling in the wards.

METHOD OF TREATMENT

The method of treatment is based on the principle of closed drainage, with the addition of tidal irrigation which is carried on by the normal respiratory movements. The tidal irrigation prevents obstruction of the tube in the majority of cases, thus removing the greatest objection to the closed method. The only fluid that goes into the chest is drawn in by the inspiratory effort. With expiration there is a partial collapse of the thoracic cavity, and the flow of fluid through the thoracotomy tube is reversed. If an opening in the tube is plugged with fibrin during expiration, the reversed flow of fluid with inspiration will wash the obstacle away. The clumps of fibrin are eventually broken up by this motion and are thus evacuated. As the tube should have

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* From the Surgical Department of the Johns Hopkins University and Hospital.

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1. Hart, Deryl: Acute Empyema: Treatment by Continuous Tidal Irrigation and Drainage Dependent on Normal Respiratory Movements, Arch. Surg. **17**:102 (July) 1928; Empyema: A Method of Treatment by Tidal Irrigation and Suction with Results Obtained in Thirty Cases, Internat. Surg. Digest, vol. 7, no. 1.

2. All statistical data are based on the first thirty-five cases except where it is specified that one of the fifteen recent cases, in which the patients are still under treatment or observation, is being discussed.

two or more openings near the inner end, the chance of all becoming obstructed at one time is remote.

In order to carry out the method of treatment, only a reservoir of fluid is needed which has an airtight connection by means of a rubber tube with the empyema cavity (fig. 2). For simplification of the post-operative care, provision can be made for emptying and refilling the reservoir (figs. 1 and 2). Suction can be applied to the empyema cavity by lowering the reservoir, or by lowering the pressure within the reservoir (figs. 1 to 3). In the first cases in which this method of treatment was employed, a rubber bag was used; it was strapped to the abdomen

Fig. 1 (patient 16).—Irrigation and suction apparatus used in the treatment for acute empyema complicated by a bronchial fistula.

to give it a dependent position.[3] A T-tube was used to connect it with the chest and to make provision for emptying and refilling. This bag was not suitable for use in the presence of a bronchial fistula since there was no way to eliminate the air. A flask with an opening near the bottom was substituted for the rubber bag, and a vent was placed in the top.[3] This arrangement permitted the escape of air, or served as a connection for the application of suction as soon as this was desired (figs. 1, 2 and 3). This apparatus can be used on patients with a large thoracotomy wound by covering the opening in the chest with a

3. Hart (footnote 1, first reference).

thin rubber dam through which the thoracotomy tube passes by an air-tight connection. Sufficient suction must be maintained at all times to hold the rubber against the chest, thus preventing leakage (figs. 1 and 3).

An apparatus illustrated by figure 4 has been used, and is well adapted to the chronic case in which the cavity is difficult to obliterate. In the more acute cases, irrigation with this apparatus is at times less satisfactory because of the length of the column of water which must be moved to permit the inflow and outflow of fluid. The tendency in this method is toward too rapid obliteration of the cavity, thus causing pocketing. In the chronic case, the cavity cannot be rapidly obliterated, and since this apparatus causes less restriction of the movements of the patient, it is more satisfactory in this type of case. It is possible for patients to be up in a chair as desired without interfering with the irrigations.

In the average case in which this method of treatment is used, there is no leakage from the cavity but only the secretions from the small granulating wound. However, in a few cases limited to small children there was definite leakage, usually beginning from about the seventh to the tenth postoperative day. In two cases the leakage was thought to be due to faulty operative technic, causing bacterial infection and sloughing of the tissues. The wall of the chest of the small child is thin, so that the granulating sinus is short. In most cases, however, the fluid seemed to be pumped out by the respiratory movements. Fluid was drawn in by inspiration, the holes in the catheter were closed at the beginning of expiration, and compression of the cavity by expiration forced the remaining fluid out around the tube. In one case this condition was controlled by inserting a mushroom catheter. No harm has resulted from this leakage. A pad can be placed beneath the patient to care for it. The leakage seldom lasts for more than a few days as the cavity is usually almost obliterated at this time, and it can usually be controlled by a careful regulation of the suction. The incision in the skin through which the trocar is inserted is made sufficiently large so that any leakage about the tube will have an unimpeded outlet to the surface.

In the acute cases, the irrigation was carried on for an average of twenty days. In most cases the irrigation practically stopped within fifteen days, but the apparatus was left in place for from four to seven days longer to give the lung time to become firmly adherent. Otherwise, as soon as suction is released the lung will pull away, the cavity will enlarge and the temperature will rise. In the chronic cases, the irrigation was continued as long as seventy days without leakage. In these cases there was little or no redundant granulation tissue about the opening of the sinus.

ADAPTABILITY OF TREATMENT TO TYPES OF CASES

Age.—The treatment has been found to be satisfactory for patients of any age. However, as already noted, the possibility of leakage around the tube is somewhat greater in small children than in adults. It is unusual for any leakage to occur around the tube in older children or adults.

Duration of Empyema.—The simplest type of patient to treat is the one with massive empyema of sufficiently long duration to prevent an immediate expansion of the lung. In these cases, a moderate amount of suction can be applied from the beginning of the treatment.

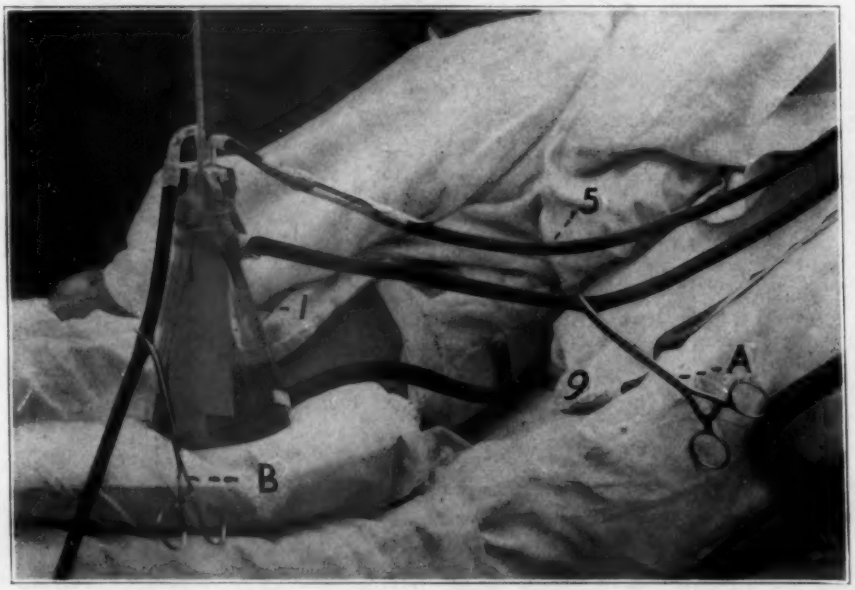

Fig. 2 (patient 16).—A close view of the irrigation flask, *1*, and its connecting tubes. Clamp *A* closes the tube by means of which the irrigation flask is refilled from the bottle, *2* (fig. 1), and clamp *B* closes the syphon tube through which the flask, *1*, is emptied into the drainage bottle, *3* (fig. 1). The tube, *5*, goes to the suction unit (fig. 3), and the tube, *9*, goes into the empyema cavity. The latter tube passes through a small hole in a piece of dental dam, an airtight closure is obtained by the contraction of the rubber, and the thoracotomy wound is closed by means of the suction holding the rubber dam against the skin which had been rubbed with petrolatum. A small dressing is placed over the dental dam and the wound. The tube, *9*, is longer than was generally used, but even with this length the irrigation is satisfactory. The flask, *1*, is suspended so that it will swing with any movement of the patient's body.

With a small amount of suction there is practically no possibility of leakage so long as the tube does not become obstructed. In all cases, however, a period of from a week to ten days should be allowed for

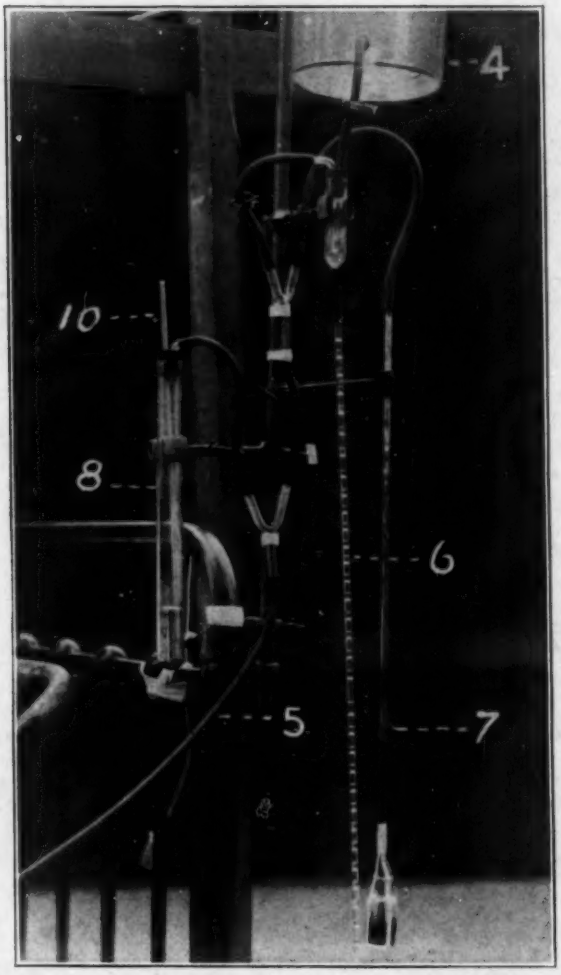

Fig. 3 (patient 16).—The suction unit consists of a Connell apparatus, *4* and *6*, with a water manometer, *7*, and a reversed mercury manometer, *8* and *10*. The suction was obtained by the water dripping from the reservoir, *4*, through the upright tube, *6*. Air was trapped beneath each drop of water and eliminated from the system. As soon as this elimination exceeded the inflow through any leak, such as a bronchial fistula, suction was obtained. When the pressure within the system plus the weight of the column of mercury in the cylinder, *8*, above the lower end of the upright glass tube, *10*, was less than atmospheric pressure, air was forced in through the tube, *10*, and the mercury. This vent prevented any further increase in the amount of suction as long as the tube, *10*, was set at that level, but changing the position of the tube, *10*, permitted the accurate regulation of the suction to any desired amount. Whenever the pressure within the system became greater than atmospheric pressure, as when fluid was run in from the bottle, *2* (fig. 1), the air bubbled out through the water manometer, *7*, in addition to being eliminated through the tube, *6*. Without the valve, *11*, the top of which is just visible in figure 1, the Connell apparatus was not satisfactory for suction in these cases. This valve, which was kept beneath the fluid in the drainage pan, permitted the free escape of fluid and air but prevented any back suction with respiratory movements. Otherwise, with the wide excursions of the drops of fluid with respiratory movements, the fluid in each drop would become attached to the side of the tube, destroying the diaphragm effect and permitting air to enter.

Fig. 4.—A type of apparatus very satisfactory in semichronic cases, but in acute cases it tends to obliterate the cavity too rapidly, thus favoring pocketing. Irrigation is limited because of the length of the column of water which must be moved before the fluid can flow into the chest. Also, if the tube is permitted to hang down as shown in the illustration, the back flow from the waste end during inspiration gives an increasing disproportion between the height of the columns of fluid in the descending and ascending parts of the tube and consequently a rapid increase in the amount of suction. Air is not readily eliminated around this loop, and when it accumulates in the descending tube it may counteract the amount of suction as recorded by the water manometer. A continuous current of fluid down the tube passes back and forth into the chest and any pus is swept down and out. The irrigating fluid drips through the upright tube, and gives suction. The other parts correspond to those in figure 3. The addition of the bottle is to give volume to the system under decreased tension, thus stabilizing suction in the presence of the respiratory movements. The partially concealed tube near the reversed water manometer is added for the connection of a supplementary suction unit if such is available and desirable. The great advantage of this unit in chronic cases is that it does not cause such great restriction to the movements of the patient. At the same time, irrigation is satisfactory since the cavity cannot be rapidly closed, while the slow and forceful respirations carry on an efficient tidal flow.

irrigation without any attempt being made to obliterate the cavity. This delay permits cleansing of the cavity and clearing up of the infection in the granulating wall. The suction is then increased to any desired amount, but it is seldom that more than from 15 to 20 cm. of water is needed, even in the chronic cases of long standing.

In the acute cases, no suction is applied in the early part of the treatment. After the first twenty-four to forty-eight hours, when the sinus is fairly well established and there is less danger of extravasation into the tissues, from 2 to 3 cm. of positive pressure may be used. This slight pressure prevents too rapid obliteration of the cavity, and when there is leakage, this material will find its way out around the tube. When leakage occurs, the positive pressure should be reduced. It is also desirable in these cases to fill the cavity several times a day in order to open up all recesses and prevent any sealing off of pockets until the granulating surface is entirely free from infection. After ten days it is safe to begin the obliteration of the cavity by suction, though it will frequently be almost closed at this time.

In the chronic cases, the cavity is irrigated with surgical solution of chorinated soda (Dakin's solution) in the early stages to eliminate as much as possible of the redundant granulation tissue. Suction can be applied from the beginning of the treatment, and a larger amount can be used than in the acute cases. Cavities of from eight to twelve months' duration have been obliterated rapidly, and the results suggest that in patients with empyema of much longer standing cure may be obtained by this method, used alone or in association with plastic operations on the wall of the chest.

Condition of Patient.—With a very ill patient, the operation can be performed without taking him from the room or the bed. Two patients have been operated on while in an oxygen tent. Following operation, such a patient is not disturbed by frequent, long and painful dressings. For a patient who is not so ill, provision can be made so that he can sit up in bed or even in a chair. A patient with tuberculous empyema who is now under treatment spends all of his days out of doors in the sun.

Type of Organism and Pus.—The type of organism causing the infection and the character of the pus with which one has to deal make little difference.[4] With very thin pus the danger of extensive extravasations is greater unless all pressure within the cavity is released,

4. The organisms encountered, with the number of cases of each, are as follows: Pneumococcus, 19 (type I, 3; type II, 3; type III, 1; group IV, 9; not typed, 3); streptococcus, 11 (hemolytic, 7; nonhemolytic, 4, 3 of which were viridans); staphylococcus, 8 (aureus, 6; albus, 1; citreus, 1); colon bacillus, 1; influenza bacillus, 1; diphtheroids, 1.

while some difficulty may arise from obstruction of the tube when the pus is very thick. However, pus which is so thick that difficulty is encountered in aspirating it through a no. 20 French catheter may be gradually worked out by the force of the frequently repeated respiratory movements. An exceptional condition is found when the lung expands quickly so that the parietal and the visceral pleural surfaces are in contact. The cavity in which there is practically no fluid is suddenly flooded with large quantities of exudate which is dislodged from the pleural surface. This sudden release of exudate and fibrin may

Fig. 5 (patient 16).—Roentgenogram of the chest of a man, aged 26, taken twelve hours after a gunshot wound of the chest and abdomen. In addition to left hemothorax, there was a large abdominal hemorrhage from perforation of the liver and the stomach. Note the marked displacement of the trachea and the heart to the right. Aspiration was done twice, on the third and fourth days, for relief from the respiratory embarrassment. The cultures showed a mixed infection, hemolytic streptococcus, *Staphylococcus aureus* and the colon bacillus being isolated. Trocar thoracotomy was performed on the fifth day.

occur at any time from the first few hours to several days after treatment is instituted, and is most frequent in the cases of pneumococcus empyema.

A certain amount of manipulation may be necessary to evacuate this material. It is best accomplished by running in enough fluid to suspend the solid material and then letting it run out. When the tube is plugged, the material is broken up by a churning force obtained by alternately compressing and releasing the tube. In a few cases this procedure has been necessary, but it never requires more than fifteen minutes and is never needed more than once for any one patient. When the organism is a hemolytic streptococcus, any slight trauma or operation may cause a severe temperature reaction. The patients with staphylococcus

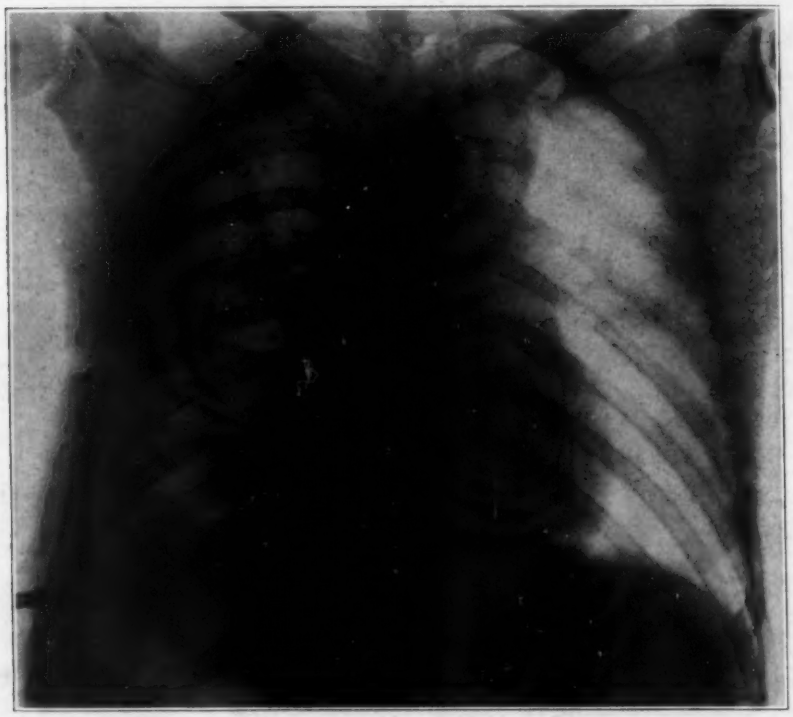

Fig. 6 (patient 16).—Roentgenogram taken forty-eight hours after trocar thoracotomy with the institution of tidal irrigation. For twenty-four hours there had been sufficient leakage of air into the system to suggest a small bronchial fistula. This became much more pronounced, and four days after this roentgenogram was taken a rib was resected in order to obtain dependent drainage (fig. 7). This was necessary because the irrigation system, as used with a rubber bag, became distended with air so that it was unsatisfactory. In the presence of a virulent infection (fig. 11), rib resection was considered necessary as a life-saving measure.

empyema are particularly liable to develop metastatic abscesses (figs. 20 to 23), a complication which occurred in three of these patients, all of whom recovered.

TECHNIC AND RESULTS

Thoracotomy.—In forty-seven of the fifty patients treated up to this time, only trocar thoracotomy has been performed. None has developed an abscess along the drainage tract. A second trocar thoracotomy was performed on four of these patients, only three of whom are included in this report. In one, the first tube was not in the pocket. Two others had more than one pocket, so that the temperature was not reduced following drainage of the first cavity.[5]

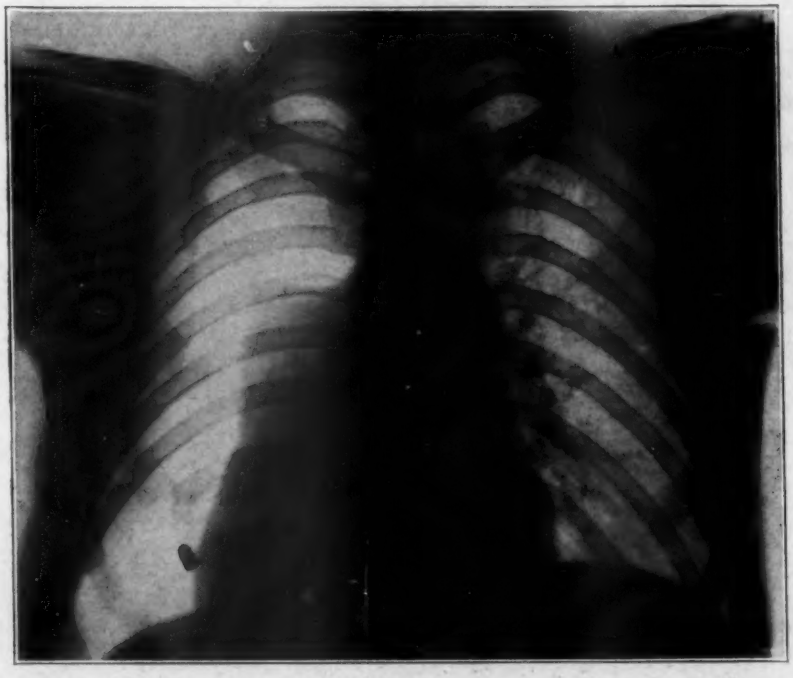

Fig. 7 (patient 16).—Roentgenogram taken seventeen days after resection of the ribs. On account of the fulminating character of the infection (fig. 11), the resection was more extensive than usual in order to secure absolutely dependent drainage. The temperature soon fell to normal (fig. 11), but there was persistent pneumothorax with the left lung completely collapsed and the heart and trachea displaced to the right. There was a large amount of purulent discharge.

It is felt that the manner in which the operation is performed has much to do with the postoperative course. Every effort should be made to place the tube in the most dependent part of the empyema cavity

5. In a patient now under treatment in another hospital, without close personal supervision, the cavity was obliterated too rapidly, and a pocket was walled off posteriorly. Following drainage of this through a trocar thoracotomy, the temperature became normal and improvement has been uninterrupted.

(figs. 4 and 14), and at the same time every precaution taken to cause the minimum amount of trauma and to prevent the extravasation or spreading of pus through the tissues. It is desirable in such a case to have the patient in a moderate to full Fowler's position, both for his respiratory ease in the early stages and for his comfort during the day in the latter part of the treatment. The most dependent part of the chest with this position is about in the midaxillary line. Furthermore, it adds much to the patient's comfort to be able to lie flat on the back

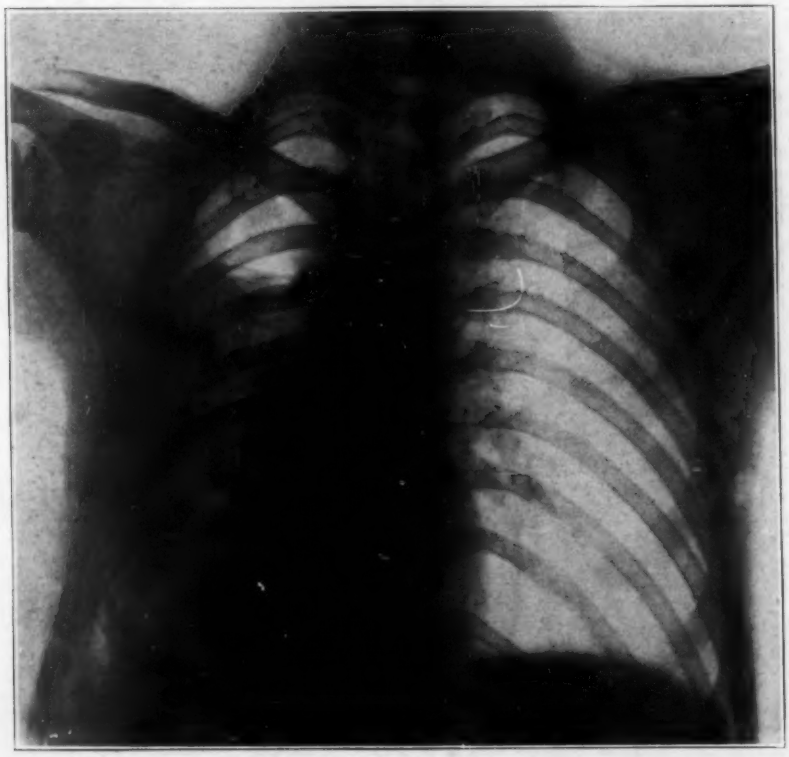

Fig. 8 (patient 16).—Roentgenogram taken three days after that shown in figure 7, and forty-four hours after the institution of tidal irrigation and suction (figs. 1 to 3). The lung has expanded except at the apex and the heart and mediastinum are back to the normal position. There was a moderate rise of temperature (fig. 11), but the patient's general condition was satisfactory. There was considerable pain for the first few days, but after this was over the respirations were normal in rate for the first time following his injury.

without the pain from pressure on a thoracotomy tube. Accordingly, in massive empyema, with the patient lying on the back a line is drawn where the skin comes in contact with the bed, and the thoracotomy is performed just anterior to this line. This assures the patient two com-

fortable positions (back and opposite side), and also insures that the tube will not be obstructed from the pressure of the patient's body (figs. 1, 4 and 17 *B*).

The point chosen, usually in the eighth interspace, is infiltrated with procaine hydrochloride, care being taken to do all infiltration as the needle is gradually passed in, and to force no fluid out as the needle is withdrawn after it may have become contaminated by piercing the

Fig. 9 (patient 16).—Roentgenogram taken fourteen days after the institution of tidal irrigation and moderate suction in the presence of an open thoracotomy wound. The lung had expanded except for a sinus holding 40 cc., the temperature and respirations were normal, and his general appearance was markedly improved.

infected pleura. At times, when the pus is thin, it is aspirated through this needle, which is left in place. Otherwise the needle is withdrawn, and a larger, aspirating needle is inserted through the periphery of the infiltrated, button-like area. As soon as the needle is between the ribs, determined by palpation, or by "feeling" the rib with the point of the needle, it is directed sharply upward so that the point is kept near the wall of the chest. When the needle is inserted very low, one thus

avoids piercing the stomach, spleen or liver. If pus is not obtained at a depth through which one would feel free to pass the trocar, the needle is withdrawn and inserted in a similar manner one interspace higher. It is unwise to pass the needle to a great depth, strike pus, and withdraw the infected material through uninfected tissue.

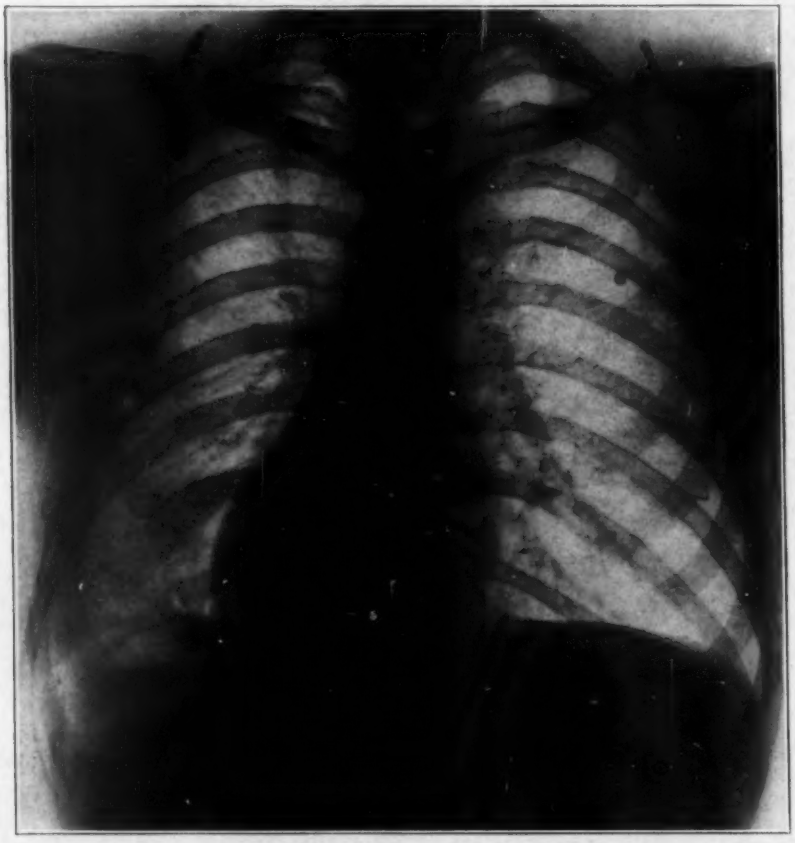

Fig. 10 (patient 16).—Roentgenogram taken seventy-two days after the institution of tidal irrigation and moderate suction, for empyema and pneumothorax of twenty-nine days' duration. The patient was discharged from the hospital, entirely cured, thirty-five days after this method of treatment was begun. The wound from the resection of the ribs was completely healed. Note the return of the contour of the chest to normal, with little thickening of the pleura.

When pus is encountered, a sufficient quantity is removed to relieve the marked positive pressure but not to give a negative pressure of any great extent. This procedure insures that the pus will not be forced out around the needle or trocar, leaves a sufficient quantity of pus so that the cavity can be easily entered with the trocar, and avoids too

great a disturbance of the protective wall of granulation tissue. The needle is left in place so that it plugs the hole through which it was inserted. This prevents the extravasation of pus when the patient strains or cries, acts as a pointer indicating the position and depth of the pus, marks the interspace through which to insert the trocar and anchors the layers of the wall of the chest so that the trocar can be passed directly through. The anchoring of the tissues is of the greatest help when the skin is freely movable, or when there is sufficient infiltrated subcutaneous tissue to make palpation of the ribs unsatisfactory.

In the center of the infiltrated area and over the interspace through which the needle passes, a stab wound is made extending through the skin, and of a length corresponding to the diameter of the cannula. The trocar and cannula are now placed with the point in the stab wound, and parallel to the needle, which has been held by the nurse or an

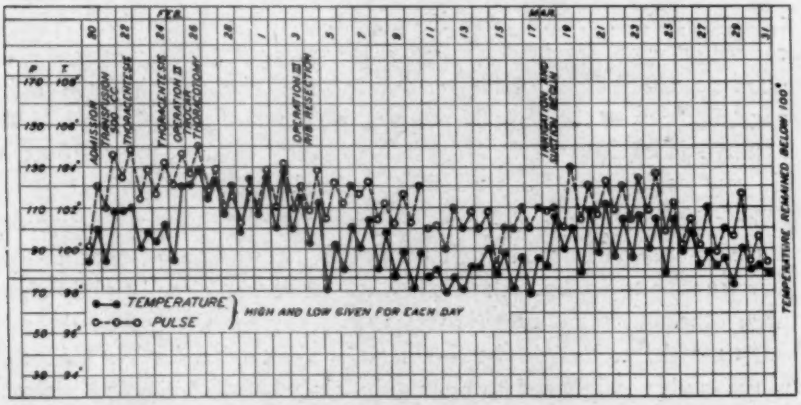

Fig. 11 (patient 16).—Temperature curve showing the rapid pulse and high temperature from the time of admission, and uninfluenced by trocar thoracotomy and tidal irrigation. The closed apparatus with a rubber bag was entirely unsatisfactory in the presence of a bronchial fistula. The temperature quickly fell following resection of the ribs, but with a moderate rise following the too rapid application of suction. This was not alarming, however, and it soon fell and remained normal.

assistant. It is carefully forced into the chest, being stopped as soon as the end of the cannula is within the empyema cavity. This point can be determined by feeling the instrument slide in the cavity as it punctures the pleura as well as by knowing the depth at which pus was first encountered with the needle.

A new catheter, size no. 20 French, with a hole on either side near the tip, marked at a point the length of the cannula from the proximal hole, clamped at the funnel end to prevent the leakage of air, and fitting the cannula so snugly that it must be oiled in order to pass

through it, is now inserted until the mark is even with the outer end of the cannula. This insures that both holes are within the empyema cavity but that the catheter is not inserted so far that it will have to be withdrawn. Any withdrawal increases the chance of spreading the infection into the wall of the chest. The end of the catheter is now placed below the surface of a bowl of warm sterile physiologic solution of sodium chloride, or a funnel (Chetwood syringe without bulb) is attached and partially filled with this solution. The end of the catheter is placed from about 2 to 3 inches (5 to 7.6 cm.) below the level of the thoracotomy wound, and held there until all positive pressure or excess negative pressure is relieved and until it is seen that there is a free tidal flow with respirations. The catheter is clamped at the end of an expiration and held in position, the cannula and the needle are withdrawn and the catheter is again clamped just before it enters the wall of the chest. It is cut off if there is an excess length that is not needed for its attachment to the irrigation apparatus (figs. 2 and 4). After it is connected with the sterile apparatus so arranged that air cannot enter the chest, a small dressing is placed about the tube, and the tube or the apparatus strapped to the body. From this time on the passage between the empyema cavity and the tidal irrigation bag or flask is kept open to avoid any positive pressure within the chest.

Resection of the Ribs.—The two patients [6] on whom early resection of the ribs was performed, each for massive empyema, present a striking contrast. In the first, the wall of the chest was closed tightly about a large tube and tidal irrigation was used for the first seven days, at which time the wound broke down on account of infection. At that time the cavity had closed to a sinus holding 40 cc., and was estimated as being about the size of the tube. In the second patient, on whom open drainage was used, there was complete left pneumothorax, with the heart and the mediastinum displaced to the right (figs. 5, 6 and 7), seventeen days after the resection of the ribs. It might be argued that the complication of a bronchial fistula was responsible for this condition. However, when the tidal irrigation and suction were adapted to this particular case, there was rapid expansion (figs. 8 to 10), the cavity closing to a sinus holding 35 cc. within fourteen days.

In the presence of the bronchial fistula, the glass flask as a reservoir was used as a basis on which to work (fig. 2). The opening in the chest was closed by placing a dental dam over the skin which had been rubbed with petrolatum. A small opening in the center of the rubber

6. In the third case, one of chronic empyema with a large cavity of eight months' duration, the rib was resected on the thirty-fifth postoperative day for relief from pain caused by pressure of the drainage tube on the intercostal nerve. The cavity held only 35 cc.

dam was stretched until a large tube could be passed through, and with contraction this gave an airtight connection. The entire apparatus with the dental dam about the tube was sterilized, and the tube was inserted through the thoracotomy wound. The dental dam gave an airtight closure of the thoracic cavity as long as sufficient suction was applied to the tidal irrigation flask. In the absence of any other source of suction, the air vent to the tidal irrigation flask was connected with a Connell apparatus (figs. 1 to 3). This was immediately thrown out of commission by the rapid and wide excursions of the drops of water in the upright tube associated with every respiratory movement. The

Fig. 12 (patient 12).—Roentgenogram of the chest of a girl, aged 11, taken two days before operation. There is a massive streptococcus empyema of the right side, complicating pneumonia. She was treated by trocar thoracotomy and tidal irrigation at the earliest possible time, and about four days after the probable onset of the empyema. Improvement was rapid and uninterrupted.

lower end of the tube was then placed below the level of the fluid in the drainage basin, and a valve placed on the end, allowing the escape of air and fluid but preventing any sucking back with inspiration. This arrangement adapted the Connell apparatus to this continual variation of pressure, and the apparatus was run sufficiently fast to more than counteract the leakage from the bronchial fistula. If a large bottle is connected so as to increase the volume of the system under decreased tension, it will stabilize the wide variations in pressure associated with the respiratory movements (fig. 4).

A water manometer (figs. 1 and 3, tube 7) was attached so that the amount of suction could be determined at any time. The lung expanded rapidly (figs. 7 to 10) and the fistula closed within thirty-six hours. The reversed mercury manometer (figs. 1 and 3, cylinder 8) was then added to permit the entrance of air when a certain suction was obtained and thus regulate the maximum suction. The long glass tube (10, fig. 3) open to the outside air could be forced to any depth below the surface of the mercury. When the suction was sufficiently great to cause the displacement of the mercury downward for this distance, air would bubble in through the mercury and no greater suction could be obtained.

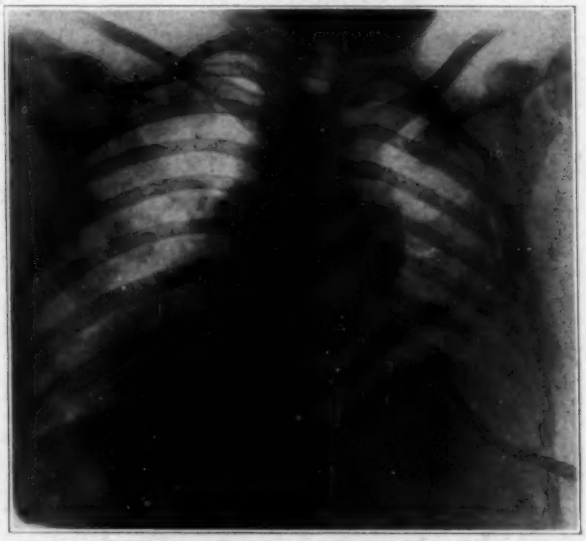

Fig. 13 (patient 12).—Roentgenogram taken twenty-four hours after trocar thoracotomy for massive empyema on the right side. The heart and mediastinum were displaced to the left (fig. 12). There had been continuous tidal irrigation, with no suction other than that given by the dependent position of the rubber bag. Note the rapid expansion of the right lung, with the return of the heart and mediastinum to their normal position. There was a certain amount of pleural pain associated with the respiratory movements, but no other untoward effects. The temperature rapidly fell to normal (fig. 16).

This tube also served as an entering vent for air when the solution was syphoned from the tidal irrigation flask. Since in most cases not more than from 6 to 8 inches (15.2 to 20.3 cm.) of suction is needed, water is now used instead of mercury. When the flask was refilled all suction was released, but the positive pressure obtained could be no greater than was required to force air out through the water manometer (tube 7, fig. 3) projecting below the level of the colored solution in the small bottle. This was about half an inch of hydrostatic pressure.

In actual use, suction had to be maintained in the empyema cavity at all times. The dental dam was held in position by a small dressing, but the watertight closure was obtained solely by suction. Any temporary release of suction meant an immediate escape of fluid into the bed. Accordingly, while suction was present the tube to the chest was clamped, the tidal irrigation flask emptied and refilled, and only after sufficient suction was present in the system, as indicated by the water manometer, was the tube to the chest unclamped. This apparatus was in use for twenty-seven days, and on only one occasion was there a

Fig. 14 (patient 12).—Roentgenogram taken on the eighteenth postoperative day. Note the marked collapse of the right side of the chest with the slight curvature of the spine. The rapid return to normal can be seen in figures 15 and 17, showing the chest about two months later. The tube is seen in the most desirable position, coming in through the costophrenic angle, and lying along the upper surface of the diaphragm.

leakage of fluid into the bed. This occurred when the Connell apparatus was broken, thus releasing all suction. The tube to the chest was changed every two to seven days in order to remove any secretions beneath the dental dam, and at no time was there any evidence of irritation to the skin. The rapid recovery in this case is told by the illustrations (figs. 5 to 11) and their legends.

Postoperative Course and Care.—Irrigation: The reservoir system of irrigation seems to be the more satisfactory. The only fluid that

enters the chest is sucked in by inspiration except for the possible occasional distention of the cavity under slight pressure to discourage any tendency to pocketing. The flask has the advantage over the rubber bag in that it can be used in cases of bronchial fistula, and permits the more accurate regulation of suction. In the early stages the reservoir is emptied and refilled every hour with warm solution, while in the later stages the interval can be lengthened, depending on the amount of drainage. For the first seven to ten days the treatment should be directed toward favoring irrigation rather than collapsing the cavity.

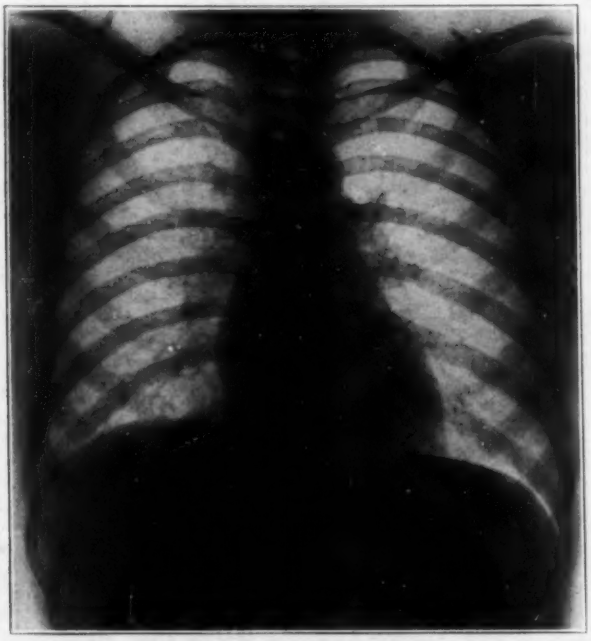

Fig. 15 (patient 12).—Roentgenogram showing the complete return to normal, with no deformity (figs. 13 and 14), practically no thickening of the pleura and the right costophrenic angle clear without noteworthy adhesions of the diaphragm to the wall of the chest. This roentgenogram was read as: "lungs clear No evidence of old empyema on the right side."

Suction: As soon as the cavity is well cleaned out, the temperature is normal, and time has been allowed for the clearing up of the infection (about ten days), suction can be applied if the cavity is not already obliterated. The simplest method is to place the reservoir below the level of the empyema cavity. In case greater suction is desired, when the rubber bag is being used, the syphon to the floor can be periodically opened for a part of the time. With the rigid walled reservoir this same system of suction can be employed by closing the air vent, or suction can be applied by the elimination of air through the vent in the top

(figs. 1 to 3). Any method which periodically applies and releases the suction is preferable to continuous suction, since the former procedure favors the occasional full distention of the cavity, and thus diminishes the possibility of pocketing. The Connell drip which I use, with provision for regulating the suction, is illustrated in figures 1 to 4.

Obstruction of Tube: The tube became obstructed with pus and exudate in a few cases of pneumococcus empyema on only a few occasions. Obstruction apparently occurred when the lung expanded sufficiently to allow the rubbing off of the thick shaggy exudate on the pleural surface. After this large quantity of exudate which suddenly flooded the cavity was removed, there was no further trouble.

One other cause of obstruction should be noted, however; when the cavity is slow in collapsing, the diaphragm becomes elevated and adhe-

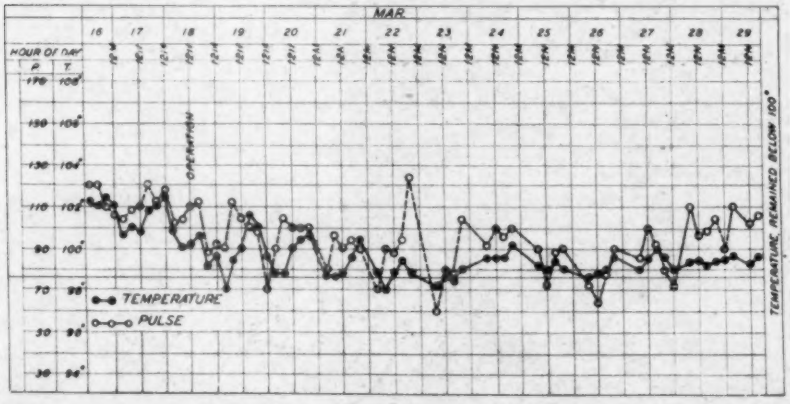

Fig. 16 (patient 12).—Temperature curve showing the rapid fall of temperature to normal within four days after operation. This, together with the course of five other patients having acute hemolytic streptococcus empyema, suggests that delay in operating is not necessary in these cases.

rent to the wall of the chest. When the tube is inserted for only a short distance at the costophrenic angle, it may become closed over, thus preventing drainage and irrigation, a condition which occurred in one of my patients on the thirtieth postoperative day, and the tube had to be inserted to a greater depth before the cavity was entered.

In a number of cases, after expansion occurred, the irrigation completely stopped when the patient lay on the back, indicating that the cavity was collapsed. When the patient was turned on the normal side, however, permitting the weight of the thoracic contents to enlarge the empyema cavity, irrigation immediately began and continued as long as this position was maintained. Early in the treatment of some patients, as much as 500 cc. of fluid ran into or out of the chest when the patient was turned. In a number of cases, after the first week, additional

suction was applied whenever the patient lay with the empyema cavity uppermost. This additional suction facilitated healing by keeping the cavity collapsed and preventing the wide excursion of the wall of the empyema cavity, thus avoiding pulmonary compression and mediastinal displacement.

The index to the collapse of the cavity has been the diminishing excursion of the particles of fibrin which can be seen in the glass connecting tube, this motion completely ceasing and the drainage becoming thicker when the cavity collapses to a sinus. From about four to seven

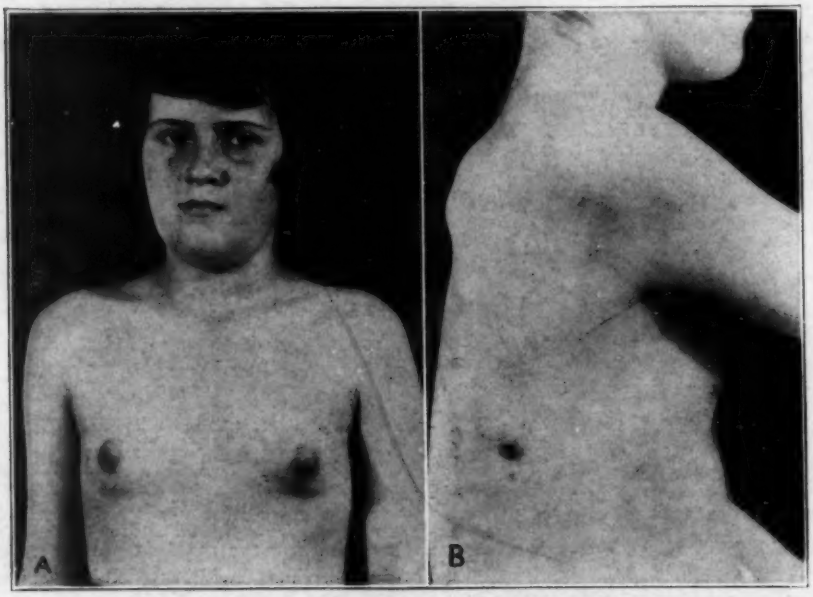

Fig. 17 (patient 12).—*A* was taken eighty-six days after operation. At this time the patient had gained 22 pounds (10 Kg.) in weight, and the chest was entirely normal to inspection and other examinations. *B* was taken four days after the removal of the drainage tube. The sinus was closed except for a small granulating area, and there had been no drainage following the removal of the tube. The scar from the thoracotomy can be seen about in the posterior axillary line, and over the eighth intercostal space. This gave dependent drainage, with the tube lying on the diaphragm (fig. 14), and also permitted the patient to lie on her back without discomfort or obstruction to irrigation.

days after irrigation ceases, the apparatus is disconnected and the tube irrigated. This time is necessary to allow the lung to become sufficiently adherent to prevent a reformation of the cavity by pulmonary collapse. If it is found that when a small amount of fluid is forced into the tube it comes out through the sinus, the tube is removed and the sinus measured. This is done by completely emptying the sinus of all fluid and

then filling it until it overflows, the tube being gradually withdrawn as the fluid goes in. This method gives a more accurate estimate of the size of the cavity than do physical or roentgen examinations.

Size of Sinus: For all patients, including those who died about the tenth day, the two with chronic infection of the lung and the one with a resection of the rib in whom irrigation was discontinued on the seventh day, the average size of the cavity at the time the irrigation was discontinued was 9 cc. For the usual case in which trocar thoracotomy

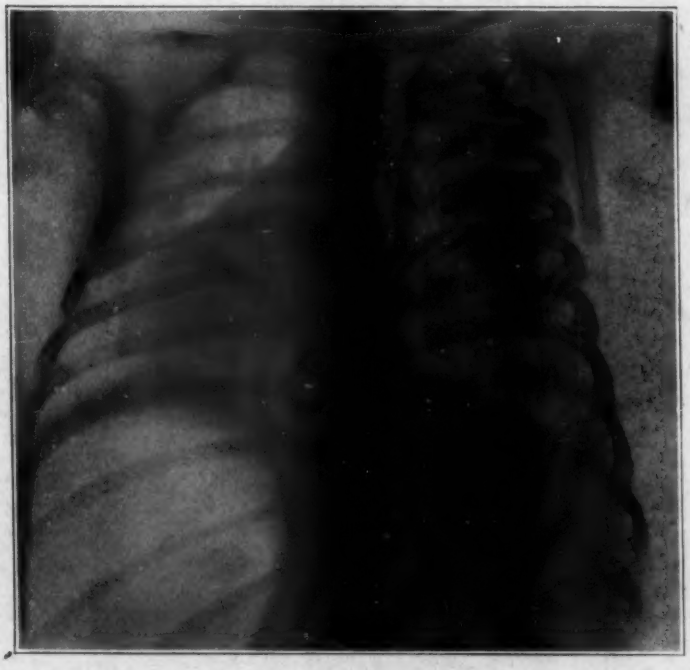

Fig. 18 (patient 1).—Roentgenogram of the chest of an infant, aged 2 months, taken on the sixth day of the empyema, and four days before operation. The empyema was a complication of pneumonia, and the cultures showed *Staphylococcus aureus*. This patient had a bronchial fistula complicating the empyema. She had been treated by periodic aspirations for ten days before operation, and developed multiple abscesses in the puncture wounds (see fig. 19).

was performed and in which the patient went on to recovery, the sinus held from 2 to 6 cc., being practically no more than the space occupied by the tube.

Time Required for Healing after Discontinuance of Irrigation: One of the patients with a chronic infection of the lung had a tube in the sinus for 112 days, the sinus healing within four days after the tube was removed. In the other patient with chronic infection of the lung, empyema of eight months' duration and bronchial fistula, the sinus

healed within seventy days after treatment was started. This saving of time was accomplished by the application of suction until the cavity was completely obliterated. In the other patients who recovered, the tube was kept in for an average of thirteen days after irrigation was discontinued. The sinus promptly healed within an average of five days after the tube was removed, the rapid closing being obtained irrespective of whether the tube had been left in place for a long or a short time.

Dressings: In over 60 per cent of the patients on whom a trocar thoracotomy was performed, the wound was not dressed for the first month except to remove the irrigation apparatus. When the cavity had

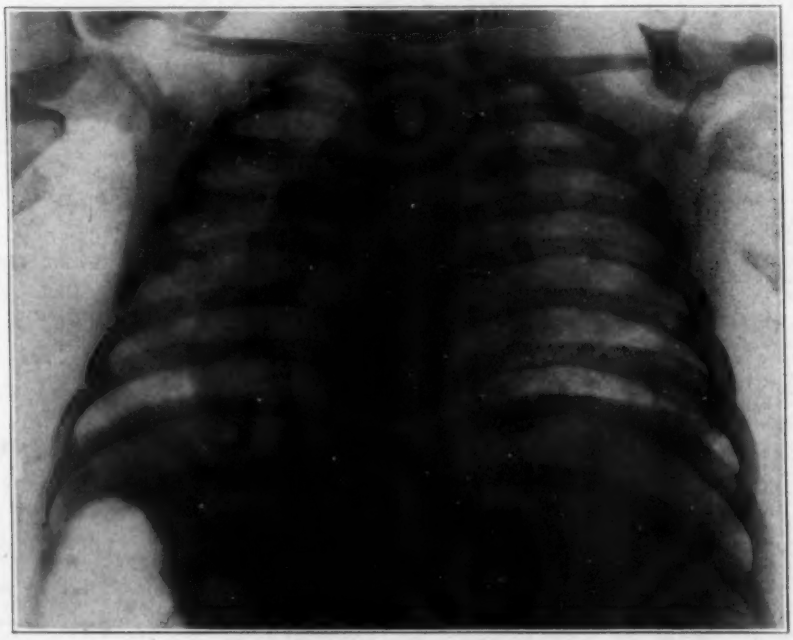

Fig. 19 (patient 1).—Roentgenogram taken forty-four days after trocar thoracotomy. A comparison with figure 18 shows the considerable growth of the patient, the clearing up of all deformity of the chest, and only a slight thickening of the pleura along the axillary border. (Both pictures were taken at 6 feet, and have the same scale of reduction in size.)

closed to a small sinus, the dressings were changed from every one to three days in order to measure the cavity to see that it was not enlarging, and to shorten the tube so as to allow closure from the bottom. In the patients with chronic empyema, dressings, after the first one, were applied from one to two weeks apart. In a patient with tuberculous empyema, the wound was dressed every week in order to cleanse the skin and restrap the apparatus to insure against the tube working back and forth and carrying infection into the chest. In the absence of leak-

age, even after the tube had been in the chest for from twenty to fifty days, there were a number of patients who did not show any redundant granulation tissue about the opening of the sinus (fig. 17 *B*).

Temperature: The temperature curve is difficult to evaluate on account of the numerous complications, particularly among children. In patients free from other inflammatory lesions, the drop to normal occurred usually within forty-eight to seventy-two hours, and the temperature remained normal throughout the postoperative course (figs. 11, 16 and 22).

COMPLICATIONS

The following list of complications not related to the method of treatment is given as an explanation of the persistent or late elevation of temperature and the consequent delay in removal of the tube: bilateral empyema, 4; pericarditis, 2; peritonitis, 2; septicemia and pyemia, 8; meningitis, 2; pyarthrosis, 1; endocarditis, 1; bilateral pneumonia, 7; chronic infection of the lung, 2; pyelitis, 3; severe infections of the skin (impetigo and furunculosis), 3; bilateral otitis media, 8; acute mastoiditis, 1; diphtheria, 2; diphtheritic myocarditis, 1; measles, 1; mumps, 1; whooping cough, 1; chickenpox, 1; syphilis, 2; acute intestinal indigestion, 1; gunshot wound with perforation of the stomach and liver and severe hemorrhage, 1; bromide delirium, 1.

The complications directly referable to the method of treatment were osteomyelitis of the ribs, 2; enlargement of the cavity following too early removal of suction, 2; severe pain from pressure of the tube on the intercostal nerve, 1. One of the patients now under treatment and not included in this report developed a pocket from too rapid obliteration of the cavity.

Streptococcus Empyema.—Cases of streptococcus empyema are considered separately because in each instance operation was advised and performed at the earliest possible opportunity. This procedure is contrary to a widely prevalent method of treatment, in which operation is delayed as long as possible, the patient being treated by repeated aspirations. The reasons for advising early operation are as follows:

1. The operation is only a slightly more extensive procedure than an aspiration.

2. There is less disturbance to the protective inflammatory zone about the collection of pus if there is a gradual and steady drainage as the lung expands rather than a forced expansion of the lung by a more rapid aspiration. Therefore, it is better to allow a gradual expansion rather than repeated expansions by aspiration, followed by a collapse from the reaccumulation of fluid.

3. There is less danger of abscesses of the wall of the chest that so frequently occur in the puncture wounds.

4. With less trauma to the wall of the chest and particularly to the protective inflammatory zone about the empyema cavity, there is less danger of bacteremia and metastatic infections.

5. Recovery is always favored by the early drainage of pus if this can be done without extensive trauma or the institution of unfavorable conditions, as a sucking wound and pneumothorax.

Of the seven patients with a hemolytic streptococcus infection, six showed immediate improvement (figs. 12 to 17), while the seventh, who had a heavy blood stream infection and signs of peritoneal irritation before operation, died within forty-eight hours. Autopsy showed pericarditis, bilateral empyema and peritonitis.

The four patients with a nonhemolytic streptococcus infection responded well to operation and recovered. One of them, however, had a stormy course due to repeated exacerbations in a basilar pneumonia occurring long after the empyema cavity was completely healed.

Bronchial Fistulas.—Seven of the patients had a bronchial fistula complicating the empyema. Six of the fistulas were of relatively recent occurrence, while one had been present for eight months. All the patients were treated by tidal irrigation, the apparatus used being that with a flask having an air vent to permit the escape of air as it came in through the fistula. With three patients, the flask was kept a little below the level of the empyema cavity to give sufficient suction to prevent aspiration through the fistula (figs. 18 and 19). With the others, including the patient with a resection of the ribs (figs. 1 to 3 and 5 to 11), suction was applied to the contents of the reservoir through the air vent. With this arrangement the flask can be placed at a higher level than the empyema cavity, thus facilitating the escape of air, while the increased height of the flask is counterbalanced by an increase in the amount of suction. In one case the fistula was closed twenty-two hours after operation, in five others forty-eight hours or less after operation, while in the sixth acute case the fistula persisted for four days. The fistula of eight months' duration was closed at the end of a week. With this rapid closure of the fistula, the course of these cases was not unlike that of the cases of simple empyema (figs. 5 to 11, 18 and 19).

Two possible explanations of this rapid closure must be considered: first, that with the expansion of the lung, the sinus through which the leak occurs becomes longer and possibly more tortuous, and therefore the air is less likely to come through, thus giving a better chance of permanent closure. The second, and the one that seems more likely, is that with the expansion of the lung and obliteration of the empyema cavity by adhesions between the parietal and the visceral pleura, the opening into the lung is sealed over by the parietal pleura. These adhesions not only close the fistula, but place the region where it occurred beyond the limits of the empyema cavity.

Complications in Children Two Years of Age and Less (figs. 18 to 23).—There have been twelve patients in this group, five of whom were less than 10 months of age, the two youngest being 4 weeks and 2 months, respectively (figs. 18 and 19). Only one (aged 15 months) died in the hospital,[7] autopsy revealing a generalized infection and bilateral empyema caused by the influenza bacillus. The condition had been recognized, and drainage obtained on only one side. The mortality over the preceding eighteen years in children 2 years of age and less was 29

Fig. 20 (patient 6).—Roentgenogram of the chest of a girl, aged 2 years, taken thirty-eight days after trocar thoracotomy and eleven days before tidal irrigation was started. (This was the first patient treated with tidal irrigation.) Thirty days after the treatment was begun, the sinus had healed and the patient was ready for discharge.

per cent in the group of patients having a resection of a rib, and in the more recent group in which closed drainage through a trocar thoracotomy was used it was 50 per cent.[8] Five patients in this age group

7. Another patient, 9 months of age, with a bilateral pneumonia, was removed from the hospital against advice, and is reported to have died at home.

8. Rienhoff, W. F., Jr., and Davison, W. C.: Empyema in Infants Under Two Years of Age, Arch. Surg. **17**:676 (Oct.) 1928.

with empyema caused by the hemolytic streptococcus have been treated in this hospital. Four died,[8] while the one treated by tidal irrigation recovered. Of the four patients in this age group with empyema caused by *Staphylococcus aureus*, three developed one or more metastatic abscesses and all recovered (figs. 20 to 23).

ADVANTAGES OF TREATMENT

Free Drainage.—The criticism has been expressed that drainage cannot be as free through a small tube as through the larger opening

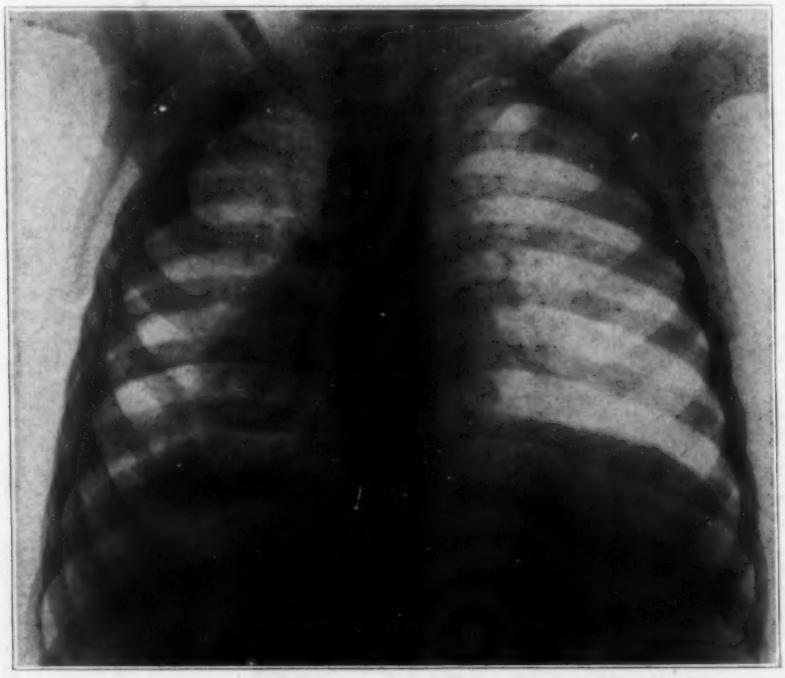

Fig. 21 (patient 6).—Roentgenogram taken sixty-eight days after the beginning of tidal irrigation. The patient had been completely well for forty days, and there is now almost no vestige of the empyema.

made by the resection of a rib. I feel that drainage is better with this method of treatment than with resection of a rib, for the following reasons:

1. Every part of the granulating surface is bathed with a relatively clean, nonirritating solution under a tension less than, or certainly not greater than, atmospheric pressure. As long as this fluid has a free circulation with the outside reservoir and as long as it bathes the entire infected surface, there is absolutely free drainage supplemented by continuous washing away of any secretions.

2. When the fluid is under a tension less than atmospheric pressure, the flow of tissue fluids to the surface should be better, and therefore there should be less absorption than when the infected surface is under atmospheric pressure.

3. In all patients who are free from complications and in whom the irrigation is satisfactory, the temperature remains lower (figs. 11, 16 and 22) than in the patients who have a granulating surface wound of equal size. The irrigation of the closed cavity with warm physiologic solution of sodium chloride keeps the wound cleaner and causes less trauma to the delicate protective granulation tissue than do compresses or any type of dressings applied to a surface wound.

Control of Collapse of Lung.—In addition to the satisfactory drainage and absence of the trauma of dressings, there is the additional advantage in the acute cases of having the collapse or expansion of the lung under control. By proper regulation of the amount of suction or of the slight positive pressure in the early stages, the rate of expansion of the lung is under control. Even in the chronic cases of not too long standing the lung can be pulled out to obliterate the dead space. The early obliteration of the cavity, after control of the infection, even by collapse of the wall of the chest and elevation of the diaphragm, is desirable since it stops the formation of scar tissue. Without scar tissue the chest will be restored to its normal size and contour by the action of the muscles of respiration. No exercises are necessary. With a large amount of scar tissue, forming where there is persistent drainage and infection, the deformity will persist and progress despite the additional muscle pull given by exercises and forced breathing.

Rapid Recovery; Absence of Persistent Deformity of the Chest.—With this method of treatment the empyema cavity was usually obliterated within from ten to thirty days, and thus was brought about a rapid recovery without persistent deformity of the chest (see all roentgenograms and photographs of patients). Usually there was an early but marked transient deformity of the chest caused by a curvature of the spine, with a falling together of the ribs and a voluntary splinting of the diseased side (figs. 13 and 14). This condition was particularly common as the rapid expansion quickly brought the pleural surfaces into contact before the formation of adhesions. This contact permitted their rubbing together, with the associated pleural pain and the resultant attempt by the patient to immobilize the chest. It has been noted already that this rubbing together dislodged the exudate over the pleural surfaces. Because of the rapid clearing up of the infection and obliteration of the empyema cavity with the minimal fibrous tissue formation, the chest quickly resumed its normal contour and movements, without any system of exercises. It usually appeared to

be normal by the time the patient left the hospital, and frequently when roentgenograms were taken from two to three months after treatment was begun there was no appreciable thickening of the pleura (figs. 10 and 15).

CONDITION OF PATIENTS AT THE TIME OF AND AFTER OPERATION

The general condition of these thirty-five patients was probably not unlike that of any other group taken at random. Most of them had acute empyema, and were very sick. It was felt that the drainage of any pocket of pus might aid the patient in the fight, so operation was performed as soon as a diagnosis was made, even in the presence of a generalized infection. Naturally, operation on this type of patients tends to increase the mortality rate among the operative cases. Two

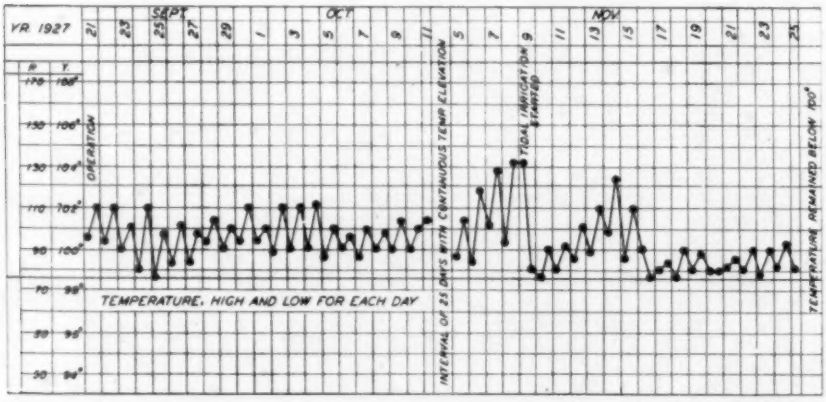

Fig. 22 (patient 6).—Temperature chart showing the continuous fever for forty-nine days, with the drop just at the beginning of tidal irrigation, and the subsequent course with only one rise worthy of note.

of the six patients who died had bilateral empyema and were operated on while in an oxygen tent. Another had ulcerative endocarditis; still another had a heavy blood stream infection and symptoms of peritonitis, the hemolytic streptococcus being the etiologic agent.

Of the patients who recovered, one had bacteremia with a pneumococcus of group IV at the time of operation, and three of the patients with empyema caused by *Staphylococcus aureus* developed metastatic abscesses.

The following notes on chronic and tuberculous empyema are given with a realization that the number of cases is too small to allow the drawing of any conclusions. However, the results to date justify further work along this line of treatment.

Other than a case of tuberculous empyema of one year's duration in which treatment is now being given, the case of longest standing was eight months. This patient had bronchiectasis and a chronic infection of the lung of twenty-five years' standing complicated by a bronchial fistula. The huge cavity healed rapidly, closing to a sinus holding 35 cc. within thirty-five days, and healing was complete within seventy days. In two other cases of ten weeks' and four months' duration respectively, healing was almost as rapid as in the acute cases. The danger of pocketing in cases of long standing is less since the cavity cannot be obliterated in a few hours with the small amount of suction used. The results in these cases have been so satisfactory that I feel that empyema cavities of much longer standing can be obliterated by this method of treatment, and that it can be adapted to use in association with thoracoplasty in the chronic cases of many years' standing. The lung can be expanded as much as possible over a period of weeks or months, and the infection brought under control. Following resection of the ribs, suction can be applied beneath the flap of soft parts, and it will hold the tissues in apposition more satisfactorily than any type of bulky and uncomfortable dressing of pads and adhesive plaster to force the soft parts in. The suction has the great advantage of application to every part of the cavity, both over the lung for expansion and to the wall of the chest for collapse. The irrigation will at the same time remove any discharges from beneath the flap.

No patient who has had either chronic or acute empyema has been discharged with a draining sinus.

Deformity of the chest of a moderate degree persisted in one chronic case. Two other patients, one with acute and the other with chronic empyema, showed in the roentgen examination some elevation of the diaphragm.

In none of these cases was there pocketing within the empyema cavity, and no patient developed an abscess along the drainage tract as the tube was removed.

Osteomyelitis of the rib developed in two patients, in both of whom healing occurred without further operation. In one of these patients a subcutaneous abscess was drained ten months after the empyema. This healed promptly and has given no further trouble.

Of the first thirty-five patients treated, twenty-nine have completely recovered and six have died. (Among the fifteen more recent cases there has been no death, and all the patients are well on the road to recovery.) Since some of the patients who died were in a hopeless condition at the time of operation, a detailed report of each case follows.

Fig. 23 (patient 6).—*A* was taken six months after the beginning of treatment. The scar on the outer side of the right leg just below the knee can be seen, while one in the left axilla and another on the inner side of the left thigh do not show. *B* shows a larger scar over the left hip. These indicate the points of incision for the drainage of deep-seated metastatic abscesses which were opened early in the course of the empyema. The patient, who had been entirely well for five months, had shown some digestive disturbance for a few days before the photograph was made. The associated herpes labialis are plainly visible. *B* was taken six months after operation, showing the scar from the trocar thoracotomy. A tube in this position prevents the patient from lying on the back or the left side; and whenever the patient rolls back, the tube becomes obstructed. The site of the thoracotomy for massive empyema was changed (fig. 17 *B*) to the posterior axillary line, at the most dependent part of the cavity.

REPORT OF FATAL CASES

CASE 1.—A white man, aged 48, with ulcerative endocarditis and septicemia (pneumococcus, type IV) at the time of operation, died on the tenth postoperative day. At autopsy, the empyema cavity was clean, lined by healthy granulation tissue, and held less than 15 cc. The microscopic sections showed little inflammation about the cavity.

CASE 2.—A colored girl, aged 10, with a heavy blood stream infection (hemolytic streptococcus) and symptoms of upper abdominal peritonitis at the time of operation, died forty-eight hours later. At autopsy, the empyema cavity was found to be practically obliterated. There was purulent pericarditis with exudate in the adjacent pleural cavity on either side, diaphragmatic peritonitis and a heavy blood stream infection.

CASE 3.—A white boy, aged 3 years, was described by the pediatricians as moribund at the time of operation for empyema on the left side four days after the right side had been drained. The operation was performed under the oxygen tent. With irrigation of both pleural cavities, with suction to keep the lungs expanded, and with the use of the oxygen tent to relieve the cyanosis and respiratory distress, there was marked improvement. After ten days, the prospect for recovery seemed good. The patient then became rapidly worse, showed signs of extensive fresh pneumonia and died. Permission for an autopsy could not be obtained.

CASE 4.—A colored girl, aged 3 years, with empyema of the right side caused by the hemolytic streptococcus, and complicated by a bronchial fistula, improved rapidly following operation. The fistula closed within twenty-two hours, and the empyema cavity was obliterated to a sinus within three weeks. Three days after irrigation was discontinued, and after three weeks with a normal temperature, the patient developed pneumonia on the left side. This was followed by left-sided empyema (pneumococcus type I). The patient died twelve hours after drainage was instituted, operation having been performed without removing the patient from the oxygen tent. Autopsy showed little pus in the fresh empyema cavity, from which several hundred cubic centimeters had been evacuated. A pericarditis and peritonitis were present, and from these pneumococci, type I, were grown.

CASE 5.—A white girl, aged 2 years, with bilateral pneumonia, was described in the admission note made by the pediatricians as moribund. Contrary to advice, on the ninth postoperative day, her parents, foreign-born and unable to speak English, took her from the hospital. She is reported to have died at home.

CASE 6.—A white boy, aged 1 year, with empyema on the right side caused by influenza bacillus, died on the tenth postoperative day with symptoms of meningitis. Autopsy revealed empyema on the left side which had not been recognized, bilateral pneumonia, pyarthrosis of the right hip and meningitis. The empyema cavity on the right side was small, clean and lined by healthy granulation tissue.

SUMMARY

Tidal irrigation between an outside reservoir and the empyema cavity prevents obstruction of the tube by washing away obstructing particles when the flow is reversed.

No fluid is run into the chest under pressure; fluid is drawn in by the expansion of the chest during inspiration.

Irrigation with a fluid at a tension less than atmospheric pressure, through a system that does not become obstructed, gives a more satisfactory drainage than does an open thoracotomy.

There is less danger of the development of osteomyelitis of the ribs than when the rib is cut across.

The rapidity of lung expansion can be regulated by the amount of suction or slight positive pressure applied.

A report is made of the first thirty-five cases of acute empyema in which continuous tidal irrigation and suction were used.

The patients varied in age from 4 weeks to 48 years, twelve of them being 2 years of age or less.

An initial trocar thoracotomy was performed in all but one of the cases. Two other patients later had a resection of the ribs, one for open drainage in the presence of a bronchial fistula (first case), and the other for the relief from pain caused by contact of the tube with the intercostal nerve.

Of the two patients in whom a rib was resected for drainage, in one the wound was closed tightly about the tube; in the other the opening was closed by rubber dam and suction. In both patients the cavity was rapidly obliterated.

There was a wide variety of organisms, but the method of treatment was equally well suited to all.

The irrigation was equally satisfactory for thick or thin pus. Even coagulated fibrin and exudate came out without obstructing the tube, unless the cavity was suddenly flooded with it.

The empyema cavity was kept cleaner than with any other method of treatment.

The average time of closure to a sinus holding 5 cc. was twenty-one days. The most rapid closure was from a massive empyema cavity to a sinus holding 7 cc. within six days.

Dressings were reduced to the minimum. Frequently there was no dressing from the time of operation until the cavity had closed to a small sinus (thirteen to thirty days).

Leakage about the tube occurred in only an occasional case even when irrigation was continued for from two to three months.

Obstruction to the tube occurred only in occasional cases, and was usually caused by thick exudate which was rubbed off the pleura; in one case it was caused by an elevation of the diaphragm with adhesions to the wall of the chest, thus closing over the end of the tube.

The sinus closed within an average of five days after removal of the tube. No patient has had a draining sinus at the time of discharge.

In uncomplicated cases there was a rapid fall of temperature to normal. Many patients had complications, unrelated to the empyema, causing a febrile reaction. At times this persisted after the empyema had healed, and delayed the final removal of the tube.

The only complication related to the method of treatment was osteomyelitis of the ribs in two cases. No patient developed pocketing [5] or abscesses along the drainage tract. The other complications were numerous, diverse and often multiple.

Patients with an empyema caused by the streptococcus were treated by early operation; rapid recovery followed with no unfavorable complications due to the method of treatment.

Seven patients had a bronchial fistula, and all recovered as rapidly as those patients with simple empyema. With the expansion of the lung, the fistula closed within the first few days, even one which had been present for eight months.

Of the eleven children 2 years of age or less with whom treatment was followed through, only one died, a mortality of 9 per cent. This rate compares favorably with the average mortality of 29 per cent with resection of a rib and 50 per cent with trocar thoracotomy over the preceding fifteen years.

The results in three cases of chronic empyema have been most satisfactory, and suggest that these cavities of long duration may be obliterated without, or at times in association with, thorocoplasty.

With the rapid recovery there was no persistent deformity of the chest except in one chronic case, and frequently there was not even thickening of the pleura.

Twenty-nine of the thirty-five patients with acute empyema recovered. The six patients [9] who died had overwhelming infections at the time of operation.

ABSTRACT OF DISCUSSION

ON PAPERS BY LOCKWOOD AND HART

Dr. Howard Lilienthal, New York: There is a slight correction that I must make for the sake of the record. I saw Dr. Lockwood's last patient in France in Base Hospital No. 3. I found him with a very bad empyema, and in a deplorable condition. I tried decortication of the lung, but aeration and expansion did not occur, and I did not dare even to close the wound because the man was in such a perilous condition. The wound was about 14 inches long and wide enough to put two fists into. There he lay, day after day, for weeks, and I could not do another thing for him.

Then I had to leave that base hospital. I came to America, and some months afterward I saw him at the Polyclinic Hospital in New York, which was then an army hospital. He looked about as he did when I left him in France.

I must congratulate Dr. Lockwood for having succeeded in such an unpromising case.

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9. To date there have been only these six deaths in over fifty cases.

Dr. Hart's apparatus interested me, but I believe that the simpler suction method of Thiersch is preferable. This is not truly a suction, but an expansion method, and is accomplished by a tube fitted with a rubber valve which prevents the entrance of air into the chest while permitting drainage of fluid and escape of air. Thiersch used a valve made of a rubber dam, but I have found an ordinary slit finger cot will do just as well. The valve is known colloquially as the flapper valve, and I cannot see that there is any great advantage in the rather complicated, extremely ingenious, method which was shown here.

My last case was that of an infant, 6 weeks old, with an acute empyema and abscess of the lungs from which foul pus was discharged by mouth. There was pneumococcus infection. That child was treated by the flapper tube method through an intercostal puncture and was entirely well and discharged from the hospital eleven days from the time of operation.

DR. DERYL HART: I have nothing further to say except in answer to the question as to the type of fluid. In all of the acute cases and some of the chronic cases physiologic solution of sodium chloride was used; in one of the chronic cases a surgical solution of chlorinated soda (Dakin's solution) was alternated with the other solution.

PROCEEDINGS

Wednesday, April 24

The council met in executive session at 8:15 p. m.

Thursday Morning, April 25

The Association met at Barnes Hospital at 9 a. m.

Operative clinics were conducted by Dr. Evarts A. Graham and Dr. Duff S. Allen, St. Louis.

Cases were demonstrated by Dr. J. J. Singer and Dr. Evarts A. Graham, St. Louis.

A short business meeting was held at noon.

Thursday Afternoon, April 25

Demonstrations were given of recent laboratory work conducted by the staff of Barnes Hospital and Washington University Medical School. Drs. Harry Alexander, William Kountz, Duff S. Allen, Evarts A. Graham, Philip Varney, I. Y. Olch, H. C. Ballon, Peter Heinbecker, S. H. Gray, J. Cordonnier, J. J. Singer, Alfred Goldman and Byron Francis participated.

Friday Morning, April 26

The meeting was continued in the auditorium of Washington University Medical School. The following papers were presented:

Dr. Emile Holman and Dr. Mary E. Mathes, San Francisco: "The Production of Intrapulmonary Suppuration by Secondary Infection of a Sterile Embolic Area."

Dr. C. M. Van Allen, New Haven, Conn.; Dr. W. E. Adams and L. S. Hrdina, Chicago: "Bronchogenic Contamination in Embolic Abscess of the Lung" and "Embolism in Bronchogenic Infection of the Lung."

Drs. J. B. Flick, Louis Clerf, Elmer H. Funk and John T. Farrell, Jr., Philadelphia: "Pulmonary Abscess: An Analysis of One Hundred Seventy-Two Cases."

Dr. F. A. C. Scrimger, Montreal: "A Case of Abscess of the Lung."

These four papers were jointly discussed by Drs. Willy Meyer, New York; Howard Lilienthal, New York; Wyman Whittemore, Boston; G. P. Muller, Philadelphia; A. L. Lockwood, Toronto; E. F. Butler, Elmira, N. Y.; E. C. Cutler, Cleveland; Kennon Dunham, Cincinnati, and in closing by Drs. Holman, Scrimger, Flick, Clerf and Van Allen.

Dr. Edward D. Churchill, Boston: "Decortication of the Heart (Delorme) for Adhesive Pericarditis."

Drs. John Alexander, A. Garrard Macleod and Paul S. Barker, Ann Arbor, Mich.: "Sensitility of the Exposed Human Heart and Pericardium."

The discussion on these two subjects was opened by Dr. Evarts A. Graham, St. Louis, followed by Drs. Howard Lilienthal, New York; E. W. A. Ochsner, New Orleans; E. C. Cutler, Cleveland; P. N. Coryllos, New York, and in closing by Dr. Churchill.

Dr. William DeW. Andrus and Dr. J. D. Wilson, Cincinnati: "The Effects of Closed Pneumothorax and Phrenicotomy on the Cardiorespiratory Function."

Dr. Charles D. Lockwood, Pasadena, Calif.: "The Treatment of Some Unusual and Difficult Cases of Empyema."

Dr. Deryl Hart, Baltimore: "Empyema: Treatment by Tidal Irrigation and Suction."

The papers by Drs. Lockwood and Hart were discussed by Dr. Howard Lilienthal, New York, and in closing by Dr. Hart.

Friday Afternoon, April 26

The Association met in executive session for election of officers, new members and such other business as was brought before the meeting.

The following papers were presented:

Dr. John L. Yates, Milwaukee: Presidential Address.

Dr. Howard Lilienthal, New York: "Direct Drainage of Tuberculous Pulmonary Cavities."

Dr. Edward S. Welles, Saranac Lake, N. Y.: "Phrenicectomy in Three Hundred Cases of Pulmonary Tuberculosis."

Dr. Ralph C. Matson, Portland, Ore.: "The Electrosurgical Method of Closed Intrapleural Pneumolysis in Artificial Pneumothorax."

Dr. Frank S. Johns and Dr. Dean B. Cole, Richmond, Va.: "Therapeutic Pulmonary Collapse."

These five papers were then discussed by Dr. Edward S. Welles, Saranac Lake, and in closing by Dr. Matson.

Drs. R. H. Overholt, George P. Muller and Eugene P. Pendergrass, Philadelphia: "Postoperative Pulmonary Hypoventilation."

This paper was discussed by Drs. G. P. Muller, Philadelphia; Kennon Dunham, Cincinnati; Willy Meyer, New York; Evarts A. Graham, St. Louis; P. N. Coryllos, New York; J. J. Singer, St. Louis, and in closing by Dr. Overholt.

Saturday Morning, April 27

The meeting convened at 9:10 a. m.

The following papers were presented:

Dr. C. C. Macklin, London, Ontario: "Functional Aspects of Bronchial Muscle and Elastic Tissue."

Dr. William Hudson and Dr. Hans A. Jarre, Detroit: "Cin-Ex Camera Studies of the Tracheobronchial Tree," with motion pictures.

The discussion on these two papers was opened by Dr. Evarts A. Graham, St. Louis, followed by Drs. Macklin and Hudson, essayists.

Dr. Stuart W. Harrington, Rochester, Minn.: "Surgical Treatment of Intrathoracic Tumors."

Dr. Pol N. Coryllos and Dr. George L. Birnbaum, New York: "The Circulation in the Compressed, Atelectatic and Pneumonic Lung."

Dr. Emile Holman, San Francisco, opened the discussion, and Dr. Coryllos closed it.

Dr. James Greenough, Cooperstown, N. Y.: "Operations on the Innominate Artery: Report of a Successful Ligation."

The discussion was opened by Dr. John Alexander, Ann Arbor, followed by Dr. Emile Holman, San Francisco. Dr. Greenough closed the discussion.

Dr. Edgar W. Phillips and Dr. W. J. Merle Scott, Rochester, N. Y.: "The Surgical Treatment of Bronchial Asthma."

CHANGES IN CONSTITUTION AND BY-LAWS

At the twelfth annual meeting of The American Association for Thoracic Surgery, Article IV, Section 2, of the By-Laws was amended to read as follows:

"Active Membership shall be limited to 100. The candidate, to be eligible, must be resident in the United States or Canada, must be a graduate in medicine of not less than ten years' standing, and must have made a meritorious contribution to knowledge pertaining to the thoracic field. *In unusual circumstances the ten-year requirement will be waived.*"

The amended portion of the section appears in italicized type, and the amendment became effective upon adoption.

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1929

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In Memoriam

HOWARD A. LOTHROP

1864-1928

The American Association for Thoracic Surgery lost one of its most distinguished senior members when Howard A. Lothrop died on June 4, 1928.

He was one of the finest products of the educational institutions of Massachusetts, graduating "magna cum laude" from Harvard College and leading his class, 1891, in the Harvard Medical School. He received the degrees of Master of Arts and Doctor of Medicine. Then, after two years of study in Vienna, he served as house officer at the Massachusetts General Hospital.

Because of the excellence of his scientific work and his ability to impart knowledge, Dr. Lothrop was made instructor in surgery in the Harvard Medical School, in which capacity he served from 1903 to 1912. He was then promoted to the rank of assistant professor of surgery, which he held until 1922. From that time until 1923, he had the honor of being Acting Professor.

Dr. Lothrop was unmarried and lived with his mother, who, with his two brothers and three sisters, survives him.

He retired from the staff of the Boston City Hospital in January, 1927, but retained a large private practice.

His work on the ligation of arteries for aneurysm was one of his important contributions. He was also one of the early contributors to the knowledge concerning epigastric hernia.

Dr. Lothrop had a well deserved reputation as a skilful and conscientious witness in medicolegal accident cases.

His character was lovable and sincere, and his handsome face and youthful carriage made it hard to believe that he was born on Dec. 31, 1864.

Many interests besides medicine and surgery enriched his life. Even as a boy he was interested in natural history and had a fine collection of ornithologic examples of his skill as a taxidermist. He was a musician and had an excellent cultivated tenor voice, to which it was always a pleasure to listen. For many years he was a member of the Harvard Alumni Chorus.

His death was particularly sad. It followed two weeks after the inception of acute septicemia resulting from a safety-pin prick of his

thumb; to add to the tragedy, he was obliged to undergo an amputation of the arm. Such trials demand the highest type of character and fortitude, and Dr. Lothrop faced it all with exemplary courage.

Our Association mourns his loss and extends its deepest sympathy to his family.

NECROLOGY

1920	SAMUEL J. MELTZER LEO S. PETERSON KENNETH MACKENZIE
1921	H. H. JANEWAY JOSEPH RASONHOFF ROBERT M. BROWN ROBERT PATTERSON
1922	HENRY L. LYNAH
1923	WILLIAM S. HALSTEAD
1927	FRED W. PARHAM CHARLES H. PECK SPARRELL S. GALE
1928	HOWARD A. LOTHROP

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